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AGRICULTURE

IN SOME OF ITS RELATIONS WITH

CHEMISTRY

BY

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AGRICULTURE.

CHAPTER XXVIII.

A GLANCE AT THE HISTORY OF THE USE OF MANURES.

If irrigation be thrown out of the account, it would appear that the use of ashes, as obtained by burning trees or grass upon the land to be cultivated, was the first kind of manuring employed in most cases, if not in all cases; and in this category should be placed, doubtless, the old Celtic methods of sod-burning, which include, of course, moor-burning and the paring and burning of clay. Next came the droppings of pastured animals, and in due course the folding of sheep, the teathing of cattle and the use of dung which had accumulated in places where cattle congregate. Then the dung of animals kept up in yards and stables was used, then straw, and so on. So, too, the use of diluted night-soil, and of other kinds of liquid manure, in Belgium and Holland (as well as in China and Japan), marks an important step in agricultural development which subsequently had no little influence upon the practices of other countries.

It is noticeable that dung was obtained at first from wild vegetation, notably that from bog-meadows, pastures, and forests; afterwards it was derived from water-meadows, and, still later, from proper hay-fields; then from fallow crops and from the refuse of merchantable crops, viz. from straw, bran, brewers' grains, potato-slop, grain-slop, oil-cake, beet-cake, rice-feed, gluten-meal, and the like.

It is still true of many of the Western States of this country that the condition of agriculture is such that it is not profitable to expend labor in saving or applying manure; but it is interesting to observe that, with the lapse of time, some of the farmers in those regions, instead of actually throwing away the dung of their animals, spread it upon the grass-land, while others gradually

begin to apply some of the manure for Indian corn or for potatoes. The fact that these farmers seldom or never apply any of the manure to wheat, consists with what is known as to the liability of rank manure to injure wheat.

Straw in Manure.

The use of straw as an addition to stable-manure also characterizes one very important stage in the history of agriculture — a stage which it is always interesting and profitable to consider. In new countries that are fairly fertile, straw is often regarded as a mere nuisance and incumbrance to the farmer, which he is glad to get rid of as speedily as may be, by burning it, or by throwing it into a river if opportunity offer. Some parts of California are still in such condition that the straw of the grain-crops is burnt at once, either as fuel for heating the boilers of threshing-machines, or merely for the sake of destroying it. One great incentive to the burning of straw, especially in a dry climate, is the need of putting it out of the way of taking fire at an unsuitable time, and so doing damage to houses, or fences, or crops.

The extreme dryness of the climate of California makes the problem of dealing justly there with straw an extremely difficult one. During the larger part of the year there is not rain enough to keep the heaps of straw moist, and no way of rotting the straw has as yet been put in practice, except by bringing water to it artificially, or by making the heaps in some natural depression or miry place. But in humid climates like those of Northern and Central Europe and our own Atlantic States, there is little or no trouble in rotting straw if the farmer wishes to do so.

Straw-yards.

As a matter of history, it would seem that at a very early period straw was used for feeding and bedding cattle in rather a crude way. Thus Cato said, "You can make manure of litter, or else of lupines, straw, beanstalks, or leaves. Pull up weeds from among the crops of grain, together with the thick grass and sedge that you find growing about the willow plots. Of all this, mixed with rotten leaves, you may make a litter for sheep and oxen"; and Pliny remarked, "It is thought that in places where no cattle are kept, it is advantageous to manure the earth with stubble or even fern." In Northern Europe, one plan, often carried out even now with bog-meadow hay by Irishmen in the vicinity of Boston, was to stack the straw near the homestead, and allow the

animals to have free access to the stack, so that they could pick out what they wished, and lie upon the portions which had been pulled out and trampled upon, but not eaten. One gain in this system is, that the droppings of the animals tend to collect in one place, instead of being scattered about the field. Stack feeding is really a crude device for saving manure.

The straw-yards of old English farms, and of some farms of the present day for that matter, were little more than methodical expressions of the idea of the stack. These straw-yards were special enclosures, in which cattle were turned loose to eat straw, and to trample upon that which they did not care to eat.

According to Loudon, the straw-yard was often an enclosure at the centre of the farmyard and adjacent to the dung-pit or basin. It had sheds open to the south, and was protected by high fences from north, east, and west winds — the idea being to let the cattle work at their leisure upon the straw, to allow them to eat more or less of it according to the quality of the straw and the vigor of their appetites, and to trample a large portion of it, in any event, into the dung beneath their feet. Some idea of the amount of straw disposed of in this way may be got from the opinion expressed by an English farmer, that "By tying cows in sheds, one-half the litter that would be required in open yards is saved."

It happens occasionally on arable farms in England, situated on light land, that a certain number of neat cattle are kept in the straw-yard during winter solely for the purpose of converting straw into manure. Beside straw, these animals get a very small allowance of turnips and a rather liberal supply of oil-cake. They are sold in the spring, at no great advance over the cost price, without ever having been completely fattened, no more being expected of them than that they shall repay the cost of the oil-cake they have consumed. The idea of the farmers who practise this course is that on poor, light soils, devoted to the cultivation of turnips and wheat, the turnips had better be eaten off the land directly by sheep — both for the purpose of impacting the land and to avoid the cost of carting the roots. But when this system is pushed far enough there are not any turnips left for fattening oxen in the yard, according to the usual plan, yet a number of cattle have to be kept there in order to transform the straw.

In Germany, which is in general a much poorer country than

England, more attention has always been paid to the methodical feeding out of straw than in England; though even in Germany a large proportion of straw is used for bedding animals that are kept confined in stables throughout the year, and so goes directly to the dung-heap.

It appears to have been found out at a very early period, in a purely empirical way, that farms dressed with manure that contained plenty of straw were kept in better heart than farms which were dressed with mere dung; that is to say, than farms manured with the dung of animals that had not had access to straw, as was just now described, and had not been bedded with straw.

Undoubtedly the acquisition and formulation of this knowledge was a very slow process, but when once the conception had been fairly grasped it was not forgotten. There are to-day few rules in agriculture so firmly fixed and so tenaciously held as that familiar one which enjoins that straw must on no account be sold off a farm, but must either be eaten upon the farm by cattle, or be in some way incorporated with their dung and rotted in conjunction with the dung. According to Armsby, a ton of wheat-straw used economically for bedding city horses may result in 6 tons of fresh manure, but is not likely in ordinary practice to yield more than five tons; and in stables where no more than 1 or 2 horses are kept, or where the manure is seldom hauled away, there may not be got finally more than 2.5 or 3 tons of manure for each ton of straw expended. As has been said already, Armsby found that horses, as kept in American cities, actually produce per head and per year some 12,500 lb. of fresh manure (dung and litter together) which can be saved, allowance being made for manure dropped outside the stable. About 2,500 lb. of straw is expended annually for bedding one horse.

Straw unduly esteemed.

In many parts of Europe the owners of land have insisted, since a very early period, that no straw shall ever go off the land under any circumstances. In signing his lease, before taking possession of a farm, the tenant is bound to consume the straw of all grain crops upon the farm, and to apply it to the land in some form; just as he is bound to use upon the farm all the manure which the animals kept upon it may produce. Upon this fundamental basis modern agriculture has been built up. It has commonly been believed in recent years that the reason why straw

serves so good a purpose is that it is rich in ash-ingredients. Not only does it, like any other litter, absorb and retain large quantities of the most valuable part of the manure, i. e. the nitrogenous urine, which might otherwise run to waste, — to say nothing of potash and other ash-ingredients which the urine holds dissolved — but it is a well established fact that the straw itself contains a great mass of potash, lime, and other ash-ingredients, which have been left behind in the straw after having served their respective functions in the grain-plant and helped to perfect the seed. By carrying back the straw to the land, the farmer is enabled to use these ash-ingredients over and over again, and to escape all risk of exhausting the land of inorganic matter, except in respect to the single item of phosphoric acid, which is carried off in considerable quantity by the grain.

It should be said, however, that some observers attach much importance to the organic matter in the straw. And in the light of existing knowledge as to the action of microscopic ferments, there are good reasons for believing that the organic matter in straw may really be very valuable. So long ago as 1847, Lawes, in urging the importance of organic manures for turnips, said: "The true office of the turnip and other root crops (in rotations) consists in their converting the otherwise useless refuse of grain crops (straw) into a succulent and nourishing food for animals."

Strawy Manure helps Land hold Water.

It is known, too, that land charged with farmyard-manure is specially well fitted to absorb a great store of rain-water and to retain it in a condition available for the use of crops. In land which is habitually dressed with manure, there accumulates a vast amount of organic matter, whereby in many cases not only the porosity but the absorptive and capillary power of the soil are largely increased. It is a familiar fact that the power of light soils to hold water may be increased by applications of manure, and it has been repeatedly noticed of clayey soils also that dressings of strawy manure may enable the land to retain much moisture, in a condition useful for the support of crops, without becoming actually wet or soggy.

In illustration of this point may be cited certain experiments made by Lawes and Gilbert, in which the amounts of water retained by manured and by unmanured land were contrasted. Operating upon a wheat-field the soil of which was a rather heavy

loam resting on clay, these experimenters determined the amounts of moisture in the soil, first at the end of July, 1868, after three months of extreme drought, and afterwards early in January of the next year, at a time when the drains of the field were running, after ten very rainy days, when there was reason to suppose that the ground was thoroughly saturated. It appeared, when the land was thus saturated with water, that that part of the field which had been dunged held much more water than the unmanured land. At the time of saturation, the land which had long been dressed with farmyard-manure, at the rate of 14 tons to the acre every year, contained 35.6 % of moisture, at a depth of six inches, while the unmanured land held 24.5 %. Naturally enough, the differences as to the amounts of water held by the two soils diminished at lower depths, but on taking the whole of the soil to a depth of 3 feet there was still found 26.7 % of moisture in the manured plot, and 23.2 % in the unmanured. At the time of drought, after the wheat-crop had pumped the moisture from the land, no great difference was detected as to the amounts of water in the two plots. Taken to a depth of 3 feet, the manured land held 11 % of water and the unmanured land 12.4 %.

On the assumption that the 3 feet of soil weighed, in the dry state, 12,000,000 lb. to the acre, and one-eighth more, or 13,500,000 lb. when wet, it appeared that each acre of the manured land held 1610 long tons of water when wet, while the unmanured land held 1396 tons; and it is to be noted that the excess of water (214 tons) in the manured land represents more than 2 inches of rain. In point of fact, the manured land, as compared with the unmanured, retained within 12 inches of the surface an excess of water equivalent to about 1.5 inch of rain. Lawes and Gilbert urge that by the time when vegetation has become active, much water would have drained out of the land, and that it would almost necessarily be less completely saturated than at the time their observations were made. But even if no more than two-thirds of the given amount of water were retained, there would still be left, especially in the dunged land, a very considerable reservoir of moisture for the use of crops.

Substitutes for Straw.

When once the whole system of European agriculture had come to be based upon the use of straw, this substance was not unnaturally regarded as in some sort a necessity, without which farming

could hardly, as people deemed, be carried on with profit. Hence a search for substitutes for straw, and the use of leaves and the rakings of woodland.

The use of leaves as a manure marks in its turn one distinct step in the history of fertilizers. It is, in fact, the point which our immediate fathers had reached here in New England, and it would perhaps be hard to find to-day a good farmer, who has lived his seventy years, who will not insist that it is good practice to collect leaves in the autumn for bedding and composting. One of the most prominent agriculturists in Germany, Professor Walz, who was for a long while Director of the Agricultural School at Hohenheim, the leading agricultural school in the world, insisted strenuously to the last that wood-raking was a very important point in the practice of good husbandry. In the second edition of his little book entitled "Dünger und Waldstreu," issued so recently as 1870, that is to say, in the face of all that was then known of the use of artificial fertilizers, Walz still clings to the old idea with great pertinacity.

For his original text, Walz discourses as follows. The complaints of farmers as to the lack of materials for littering their animals, and the consequent deficiency of manure, grow louder and louder, and are heard in many different regions; while, upon the other hand, the foresters in many districts complain that the rate of growth of wood is continually decreasing because of the too frequent raking of the woodland on the part of the farmers. Meanwhile, he goes on to say, an idea is abroad that Germany has very nearly reached the limit of her power of agricultural production, that she cannot support a larger population than now exists, and that consequently the government should encourage emigration. He then proceeds to tell how these real or imaginary evils may be met and overcome, if the farmers will but avail themselves of the means which are already at their disposal. His book is, in fact, an admirable exposition of the idea which has so often found expression in our own agricultural literature, of using thoroughly the means which are to be found at the farmer's door, i. e. the things which are known to him, and which are readily accessible.

In this way Walz sought to compose the standing dispute between the farmers and the foresters, and he insisted that a part of the plan of conducting a tract of woodland should be to make it

produce crops of rakings for the farmer's use, as well as merchantable timber and cord-wood. Among other things, he urged, as has been said, that one capital way of saving dung is to put it upon the field in the freshest possible condition. For he had found in his own experience that fresh dung goes a great deal further, i. e. it expends to much better advantage than old, well-rotted dung.

Dead Leaves contain but little Plant-food.

With regard to the composition of leaves, it should be said that there is really no very large amount of fertilizing matter in autumn leaves anyway, and that they are generally inferior to straw. Considered merely as manure, it will not be worth the farmer's while to spend much time or money in collecting dead leaves.

Of course, leaves are often useful and really valuable to the householder in northern climates as a means of banking up around sheds and barns and houses, to keep out the winter's cold; and in the same sense the leaves may sometimes be valuable for bedding animals which would otherwise not be sufficiently protected from the cold; and in either of these events the subsequent use of the leaves as manure will follow as a matter of course. But as a general rule, at least for countries that are kept free from fires, the dictum of the German foresters that woods should never be raked is clearly correct. As a means of promoting the growth of wood, the leaves have a real value which can be realized at no cost whatsoever other than the pang which some farmers might feel in bringing themselves to the determination to let the leaves alone.

But in case the leaves are regarded primarily as manure to be used upon farm-land, the cost of collecting and handling them will seem large, and the expense would, in fact, usually amount to more than the leaves are worth. Autumn leaves are necessarily comparatively poor in potash, phosphoric acid, and nitrogen, since these constituents pass out from the leaves into the body of the tree with the approach of winter, there to be held in store for the next year's use. In one sense it would be perfectly correct to say that dead autumn leaves, even those that have never been leached by rain, have been wellnigh exhausted of their most valuable fertilizing constituents. But, as is well known, considerable quantities of the less valuable kinds of ash-ingredients, notably silicic acid and lime, remain in the fallen leaves. For the best

quality of autumn leaves recently fallen from hardwood trees, and not yet subjected to leaching or decay, there may be allowed from $\frac{1}{10}$ to $\frac{5}{10}$ of one per cent of potash, from $\frac{8}{100}$ to $\frac{3}{10}$ of phosphoric acid, and about $\frac{3}{4}$ of a per cent of nitrogen; or in a ton of autumn leaves of the best quality, say 6 lb. of potash, less than 3 lb. of phosphoric acid, and 10 or 15 lb. of nitrogen of poor quality; whereas in a ton of ordinary straw there would be from 10 to 20 lb. of potash, from 4 to 6 lb. of phosphoric acid, and some 6 or 7 lb. of nitrogen, of rather better quality than that in dead leaves.

The use in the barnyard of peat, and of sods or loam taken from headlands, like the use of leaves, is evidently an outgrowth from the use of straw. This practice of using earth commends itself in general, in spite of the facts that the earth contains but little fertilizing material, and that in getting out the loam or peat a great deal of labor has to be expended for the sake of a very small acquisition in direct chemical power. For it is to be noticed that no other crop is robbed when loam is brought to the barnyard from waste places, and that labor can usually be expended upon this enterprise at times when there is little else to be done upon the farm. Moreover, the task is a more manageable one than that of collecting and storing leaves, and admits of being methodized.

Green Manuring.

Like the use of straw and other litter, the ploughing under of green crops — and especially of leguminous crops, as will be said again directly — dates from a very early period, and much use seems to have been made of this method of fertilization in some southern countries, even in the ages of antiquity.

Lime, Marl, and Soot succeed Ashes.

After straw, the use of lime and marl, and of soot, came in, in Europe, in a purely empirical way; and it is from the use of these amendments, as well as from that of ashes, that the modern practices of using artificial fertilizers have grown up.

First came bones and crushed bones, bone-meal, bone-black, and poudrette; then guano from Peru and from Ichaboe, bone superphosphate, phosphatic guano and superphosphates made therefrom and from coprolites, sulphate of ammonia, nitrate of soda, Norwegian fish-scrap, superphosphates from rock phosphates, rectified guano, American fish-scrap, and flesh-meal; and

between whiles, rape-cake and other forms of oil-cake, malt sprouts, and rags, as well as the system of feeding animals upon grain, oil-cake, and distillery slop, for the sake of improving their dung; last of all, dried slaughter-house refuse, potash salts, and attempts to gain profit by means of sewage irrigation.

A Survival of Soot Manuring.

An interesting instance of the use of soot in conjunction with straw has recently been noticed on one of the Scotch islands. On the island of Lewis, namely, the huts of the inhabitants are purposely built without chimneys, and have a roof composed of sticks upon which is laid a mass of grain stubble, which in its turn is covered with a thatching of long straw. The prime object of this thick covering is to keep out the cold; but, in the absence of chimneys, the stubble becomes perfectly saturated with soot, and every spring it is taken off and utilized as manure upon the potato-fields.

During the summer the roofs are covered only with the thin outer layer of thatch which is reserved for this purpose; that is to say, the straw is carefully taken off and replaced upon the sticks after the sooty stubble has been removed. But next autumn, when the grain is pulled, the stubble ends of it are put upon the roof. Evidently a tolerably complete manure must be got from the ash-ingredients of the straw plus the nitrogen of the soot.

How to use Artificials.

At the present time, one important lesson to be learned is how to use the artificial fertilizers to the best possible advantage in conjunction with dung; or, rather, how to supplement and eke out the dung of animals by means of artificial fertilizers in such wise that the utmost profit shall be got both from the dung and from the chemicals. It has been argued, for example, that the best opportunity for the application of artificial fertilizers, hitherto accorded to English farmers, is seen in the turnip husbandry of those light land districts where roots are fed off to sheep upon the fields.

There are special cases, of course, where it may be best, on the whole, to use artificial fertilizers by themselves, as upon fields distant from the farmyard, and in places which are steep or inaccessible, for in such situations fertilizers that are concentrated and portable may have an enormous advantage over barnyard-

manure, in respect to economy of carriage and application. Much good has been done in this way upon the chalk hills of England by employing superphosphates in alternation with the folding of great flocks of sheep. It is well to remember that 100 lb. of guano containing 9 % of nitrogen will bring to the land as much of this element as is ordinarily contained in a ton of half-rotted stable-manure, and that all the guano-nitrogen is of better quality than is a good part of the dung-nitrogen. So, too, 100 lb. of guano that contains 12 % of phosphoric acid are equivalent in respect to this constituent to two tons of the stable-manure.

An experiment by Pusey, showing the advantage of using superphosphate together with dung, has been cited in a previous chapter. From this and from other experiments upon mangolds, Mr. Pusey was led to infer that it is more profitable to use some artificial manures with dung than to use either singly. Thus, guano and woollen rags used singly added to his crop only 5 tons per acre over and above that obtained without manure; a dressing of dung added only 11 tons to the crop, and doubling the amount of dung did no good. But guano combined with the dung, and rags combined with the dung, each gave crops of 36 tons to the acre; that is to say, an increase not of 16 tons of roots — as might have been anticipated by adding together the results obtained when these fertilizers were used singly — but of 20 tons; and the crops were thought to be very large indeed, considering the quality of the land.

There is great need of studying from the chemical point of view the problem what kinds and amounts of fertilizers had better be used with the different kinds of dung. Reference has repeatedly been made already to the harmfulness, in certain cases, of rank, fresh manure, and to the high estimation in which old well-rotted manure is held for certain uses and purposes. But similar remarks will apply to each particular kind of dung, whether it be the "strong" hog-manure, the "hot" sheep-manure, the "cold" cow-manure, or the "forcing" and "heating" night-soil.

It is true of almost every locality that practical men are tolerably well agreed as to the wisdom or folly of using one or another of the different kinds of dung upon a given soil or crop. In the vicinity of Boston, for example, night-soil is reputed to be excellent for cabbages and for the free-growing squash, but not for carrots, which do best with old rotted stable-manure. It is said

that when carrots are dressed with night-soil they tend to form tops (leaves) rather than roots (bulbs). Yet there are good reasons for believing that the objection may have arisen from the application of too heavy dressings of the night-soil. It may well be true that an excellent manure for carrots might be obtained by using small quantities of night-soil together with phosphates and potash salts; and the desideratum is to know how to balance and commingle the ingredients, i. e. to find out in a general way about how much should be used of each one of the several materials in any given instance.

Dietzell has urged that for the sake of hindering the waste of the nitrogen in farmyard-manure it may often be well to put upon the manure-heap a part of the phosphate which is intended to be used upon a given field or crop, instead of applying the whole quantity of the phosphate directly to the land. He suggests that a quantity no larger than 1.25 lb. of phosphoric acid — either in the soluble or the precipitated form — might be added to every 10 cwt. of farmyard-manure; or, in cases where liquid manure is kept in cisterns, he would add 1.25 lb. of phosphoric acid, this time in the form of superphosphate, to 10 cwt. of the liquid. In order to avoid the choking of the cistern pump, he suggests that the superphosphate might be put in a basket lined with straw and hung in the cistern.

Rank Growth prevented by Artificials.

The significance of artificial fertilizers considered as supplements to farmyard-manure may be seen very clearly by considering the pains that used to be taken, in districts where high farming prevailed, to "prepare the land" for wheat and for barley. As has been stated already in the chapter relating to Dung and Urine, farmers were averse to applying barnyard-manure to these grain-crops because of its tendency to encourage too rank a growth of straw and to make the crop blight. In early times manure was usually ploughed under late in the spring upon fallow land where grain was not to be sown until the autumn, or until the spring of the next year; and in cases where manure was applied directly either to wheat or to barley, care was taken that it should be well rotted. Latterly the common plan has been to apply manure to root-crops, or to beans, or to clover, which precede the grain. But by means of light dressings of dung used in conjunction with artificial fertilizers, each one upon the crop best

suited by it, it is possible not only to manure grain directly, but to expend the manure of the farm to better advantage than was the case formerly.

It is a common practice on the continent of Europe, when winter wheat is grown as the next crop after sugar-beets which have been heavily manured, to force the wheat by dressing it with nitrate of soda in the spring; and it is found that wheat thus treated yields well, and that there are certain varieties at least which stand up stiffly even in years when wheat is apt to lodge.

The risk of using dung too freely is illustrated by the experience of many American farmers in respect to the growing of wheat. Mr. R. Russell has said of us: "Throughout the North American continent, winter wheat only grows well upon soils of moderate fertility, and such as are rather deficient in vegetable matter. . . . In America, wheat is a most uncertain crop on all rich and loamy soils, in consequence of its liability, in the hot and humid periods of this summer climate, to rust and mildew, from which diseases Indian corn is entirely exempt. . . . Both in Canada and in the United States, rust and mildew are the great enemies which the farmer encounters in raising wheat, and these diseases are far more common on new than on old cultivated land. Indeed, land becomes better suited for raising wheat after the richness is partly worn off.

"The best preventive of rust and mildew is to sow early in the autumn, for if the crop is late, the heats of July are apt to ripen it prematurely at whatever stage of forwardness it may be. . . . The most of the summer rains in Canada and the United States fall in heavy thunder-showers, attended with a high temperature. Such climatic conditions favor rust and mildew, and actually render the crops grown on rich soils so liable to their ravages that the best soils for wheat in America are those which would be considered inferior ones for the same crop in Great Britain.

"The further south I went, the poorer did I find that the soil required to be to produce a healthy crop; and although there is scarcely any winter in Alabama, a well-tillered crop seemed to be essential to obtain a healthy ripening crop of wheat, even on very poor lands.

"It is worthy of observation that it is of much importance in America to have the plant of winter wheat thick and well tillered in spring. Late tillering produces coarse and vascular stems which are particularly liable to be attacked by disease. 'Sow early to prevent rust and mildew,' I heard repeated by farmers in every part of America. . . . None the less, it is held that wheat may be sown much later in the autumn upon newly cleared land than upon land which has been in cultivation for some time. The reason given is that the richness of the new land forces the wheat to grow rapidly and longer in the autumn, and thus to make up for late sowing.

"The inferiority of the climate of America for the growth of winter wheat upon rich soils is counterbalanced, however, by the superiority of its growth upon second-rate ones. I am satisfied that,

with the same treatment, the light gravelly soils of the Genesee valley, for example, would be much less productive of wheat in England and Scotland; but then I doubt if the resources of the American climate are so great as those of the British for raising the produce of wheat on the Genesee light soils. . . . The productive powers of the (winter) wheat are no doubt more limited in America than Britain, for in the former, stimulating manures cannot be applied so freely as in the latter. . . . Both in Canada and in New York there are certain light sandy loams which have rather too much vegetable matter in them to be good for wheat, and the farmers have long ago found out that such land is better suited for spring and summer crops than for autumn-sown wheat."

Farmyard-Manure Specially Favors Weeds.

In the old days of fallow fields, which were dunged for wheat, much trouble arose in Europe from the fact that the seeds of many weeds were brought to the land in the manure. Under the influence of the manure, both the weed-seeds thus brought and those already in the soil were encouraged to grow freely, and, since many of them started at the same time with the seed-grain, the weeds sometimes seemed to do the crop almost as much harm as the manure had done it good. It was held, therefore, to be a great improvement when, in place of the bare fallow, some kind of hoed crop was manured and cultivated the year before the wheat, so that many weeds might be destroyed.

It is not improbable that some of the constituents of farmyard-manure may specially encourage the growth of some kinds of weeds, or that certain artificial fertilizers may be particularly well adapted for giving grain and other useful crops an assured start, and this hypothesis derives support from the fact of observation that crops manured with appropriate artificial fertilizers, used in conjunction with dung, often leave the land in an exceptionally clean condition, because the growth of the crop has been so vigorous that comparatively few weeds could hold way with it.

Another case where artificials may help the farmer to avoid weeds is seen in the reseeding of low-lying grass-fields. Stable-manure foul with weed-seeds may be spread upon the old sod and ploughed under out of sight, to a depth where no seeds can germinate, but where grass-roots will reach the manure in due course, while a light dressing of artificial fertilizers may be harrowed into the surface soil to ensure a good catch of grass when the seeds are sown.

Artificial Fertilizers on Roots.

In England it has been urged that one great gain in fertilizing freely for roots is that such large crops may be grown in this way that the farmer can obtain, upon a comparatively small area, all the roots he needs, so that less of the farm land will be devoted to this particular crop, and more of it become available for growing barley or other merchantable products.

As has been said already, the use of artificial fertilizers upon sugar-beets has led to many interesting experiences. It is well known that, for the production of sugar, heavy dressings of farmyard manure are objectionable, because the beet-juice is liable to become surcharged with saline matters. But for growing beets on ordinary soils some kind of manure is an absolute necessity. Hence, in many cases, light dressings of dung applied in autumn have been supplemented with 3 or 4 cwt. of guano to the acre, or with a mixture of guano, bone-meal, superphosphate of lime and sulphate of potash.

When applied in moderate quantities in the autumn to land not already extremely rich, guano greatly benefits the beet-crop, and it has been used with advantage for beets on many soils. Sulphate of ammonia also, applied sparingly in the autumn, has occasionally been used with considerable advantage for beets, but —as is the case with the other active nitrogenous manures—it tends to encourage a luxuriant growth of tops and to diminish the percentage of sugar in the roots. As has been seen already, it is generally inferior for this crop to nitrate of soda. On land already in good heart sugar-beets may well be grown without adding any nitrogenous fertilizer, but as a general rule beets need rich land, and it is conspicuously true that, in addition to stable-manure, enormous quantities of artificial fertilizers are used, on the continent of Europe, for the production of sugar-beets. Were it not for the artificial manures it would be impracticable to obtain such large crops of beets as are now usual, and the juice of the beets would yield less sugar than is now actually obtained from it.

Fertilizers should be well Balanced.

It is a point of the utmost importance that the fertilizers supplied to any given crop shall be well balanced and adapted to the special needs of this crop. The nitrogenous and the mineral matters to which the roots of the crop have access should be in such

equilibrium that the plants may grow naturally and normally without either running to leaf or tending to ripen prematurely. It is particularly wasteful, from every point of view, to apply more of an active nitrogenous fertilizer than the crops can put to use.

Even in the case of grass-land, it is not practicable to make use of any very large quantities either of nitrate of soda or ammonium salts, or even of dung or dung-liquor. Lawes and Gilbert, on applying 400 lb. of ammonium salts (containing about 82 lb. of nitrogen), supplemented with an abundant supply of all the ash-ingredients of plants, were able, it is true, to obtain 3 tons of hay per year and per acre during 20 consecutive years, but it appeared that every year much more nitrogen and much more of every one of the ash-ingredients had been put upon the land than was contained in the increase of crop over that got from unmanured land. As there was no deficiency of constituents derivable from the soil, it is possible that a better climate, i. e. more favorable conditions in respect to light, heat and moisture, might have permitted the assimilation of more carbon from the air and the plant have thus been enabled to grow better. But actually there was a tendency towards a decrease in the weight of the crops as the years went on, and a less amount of growth in proportion to the nitrogen taken up, in spite of an annually increasing manurial residue in the soil.

Doubtless the problem how best to mix manures is a somewhat delicate one, because of the great differences in the quality of land. In some localities and on some kinds of soils the application of farmyard-manure by itself has been found generally to bring good crops of wheat, while in other places the application of any considerable quantity of it has proved to be inadmissible. It was on stiff clay soils in particular that the use of fresh dung for wheat or barley was deprecated because it caused a rank growth of straw and no commensurate yield of grain; yet in some places manure has been used for wheat with success on heavy soils.

According to Tanner, farmyard-manure may be applied with advantage to wheat in all cases where the growth of straw has to be encouraged, i. e. on soils which are not fertile enough of themselves to give a good growth of straw; but on those which are predisposed to yield a rank growth of straw, the application of dung to wheat would seldom if ever be safe. Possibly, another

way of stating the matter would be to say, Do not apply much dung for wheat on rich clays where nitrification is active.

Artificials may Increase Crops.

In 1858 it was said of the light chalky soils of Norfolk County, England, that, "Competent authorities assert that this district now grows 8 bushels more wheat per acre than it did 15 years ago. Formerly all the manure that could be made on the farm was needed for turnips; now a great breadth of roots is grown with artificials, leaving a large portion of the farm-manure to be applied for wheat. It is placed upon the sod-land (clover or sainfoin) directly the hay is off or before the land is ploughed for wheat in the autumn. After ploughing, the land is firmly consolidated by wheel-pressers or rollers and the wheat drilled across the furrow. In the spring it is a common practice to top-dress the wheat with nitrate of soda and salt. . . . An enormous amount of artificial manure is now used in this district for growing roots and grain. Some years ago rape-cake, bones and the newly discovered guano were almost the only artificials known. Since then, superphosphate has superseded them all in the production of turnips. For mangolds, the favorite dressing, in addition to yard-manure, is guano and salt, and some still prefer guano for swedes; but by far the greater portion of the farmers use superphosphate. The common way of growing swedes is to apply 6 or 8 loads of good farmyard-manure to the acre and drill in 2 or 3 cwt. of superphosphate with the seed."

The use of phosphatic and potassic fertilizers, even on poor sandy soils, has often been found to be highly advantageous as a means of getting good crops of turnips, clover, peas, or lupines in preparation for grain. When fertilized in this one-sided way, and when grown at appropriate intervals of time, the crops now in question can usually obtain, from the air or from the humus of the soil, nitrogen enough for their needs; while the roots and stubble which some of these crops leave upon the land—and the condition of fermentation to which they bring the land—may serve as a sufficient manuring for moderate crops of rye or oats, such as dry land is capable of bearing. Moreover, these forage crops are fed out to animals upon the farm, and thus produce considerable quantities of manure, which helps to bring up the condition of the land.

Use of Artificials alone.

Hereafter, no doubt, the problem how to get along with artificial fertilizers by themselves, without using any dung at all, will present itself in certain localities more commonly than it has hitherto, and this question will be a difficult one to answer in a thoroughly satisfactory and economical way, for the changes as to

the mere chemical texture of the soil which may be brought about in the course of years by the use of one or another fertilizer, will have to be studied and considered, as well as the supplying of plant-food. There can be no question that the influence of saline fertilizers may be helpful on some soils and harmful on others, because of their power to coagulate colloid clay, as has been explained in preceding chapters. To solve a problem such as this, there will be needed two or three generations of farmers well grounded in scientific conceptions, and open-minded enough to weigh a prejudice and count it at something like its true worth.

Thanks to favoring climates, it will be found, no doubt, that artificial fertilizers are competent to give much better results in some countries than in others. Thus, Lawes and Gilbert, in their experiments on the continuous growth of wheat during 40 years, found in those seasons when the climatic conditions were most favorable, that mixtures of artificial fertilizers gave much larger crops, both of grain and straw, than dung. But there was a wide difference between the crops grown with artificials in good and in bad seasons. It was found, namely, that the best mixture of artificial manures gave 35.13 more bushels of wheat per acre, and nearly 2 tons more gross produce, in the most favorable season, as compared with the produce grown in the worst season. "Contrary to what might be expected, the produce on the land receiving dung, while it falls greatly in yield in a bad season, does not rise as rapidly in yield in a very favorable season. This will be seen more clearly by a comparison with the land which receives artificial manures. Thus, a plot receiving mineral manures and salts of ammonia gave, in 1879, a crop exactly the same as that of the dung — 16 bushels per acre; and the average produce of 32 years is almost identical in both cases, one being 32.75 and the other 33 bushels per acre. But in the very favorable season of 1863, the dung gave only 44 bushels per acre, while the artificial manures gave 53.63 bushels, an excess of nearly 10 bushels to the acre."

Meanwhile, it is a matter of record that in several districts in the South of Europe it has long been customary to dispense with farm animals and to depend wholly on artificial fertilizers and manual labor. In more modern times, several large clay-land farms in England have been operated with success during long terms of years by means of artificial fertilizers and steam cultiva-

tion. On these farms, little or no attention has been paid to the rotation of crops, and many crops of wheat have been taken in succession, when the price of wheat was sufficiently remunerative. All the crops have been sold to go off the farm, including straw, hay, and other forage, as well as grain, while nothing has been put upon the land except phosphates of lime and nitrate of soda. In Germany, also, several farms have been worked by means of artificial fertilizers ever since the time when guano was the most prominent commercial manure.

Leguminous Crops.

The significance of clover and similar plants as a means of enhancing fertility has already been insisted upon, in the chapter on Symbiosis. It will again frequently be referred to in the chapters relating to Rotations. It needs only to be said here that the growing of clover, etc., as a crop to precede grain, has exerted a wide-reaching influence on the progress of rational agriculture. Not only can cattle be supported upon leguminous crops that have been grown by means of artificial fertilizers, but the rankness of farmyard-manure can readily be mitigated by means of such crops. It was recognized long ago by practical men in Europe that, while there is a great risk of the crop's lodging in case wheat were to be grown on rich land which had just been dressed with farmyard-manure, there is comparatively little danger of any such accident when wheat is made to succeed a leguminous crop which has been grown on the manured land. Thanks to changes which have occurred in the nitrogenous constituents of the original manure, and to the chemical character of the nitrogenized matters which the clover has brought in, wheat may be grown readily enough after clover or the like, even when the soil is still much richer than it really needs to be for the success of the grain-crop.

Money Value of Dung.

From the time when the use of commercial fertilizers became somewhat general, the question has often been asked, How much is a ton of farmyard-manure really worth, as compared with a ton of mixed artificial fertilizers? It is not easy to give to this question a precise general answer, in view of the conditions under which farms now exist, and especially in view of the peculiarities of stable-manure, which were discussed on a previous page.

There is little use in trying to figure out the value of dung by estimating the nitrogen, the phosphoric acid, and the potash con-

tained in it at prices which have to be paid for these substances when bought in the form of artificial fertilizers; for in farmyard-manure these useful constituents are concealed and encumbered by a great mass of inert and useless matter, which makes the cost of bringing them to the land out of all proportion larger than the cost of applying the same constituents when procured in the form of artificial fertilizers. It is to be remembered withal that ordinarily some trouble and expense are incurred in applying farmyard-manure to particular crops and at certain times or stages in rotations, in order that it shall do its best service; and yet, as has been shown, farmyard-manure has some peculiarly useful qualities which are lacking in most artificial fertilizers.

As Gasparin has said, "To solve this difficult problem, it would be necessary to take into the account all the agricultural circumstances that have any bearings upon the case in hand, in order to be able to appreciate precisely how much produce can be got from a given amount of manure." And in trying experiments to test the question it would be important to arrange matters in such wise that the trial should be independent of climate and of soil, in so far as possible.

Nevertheless, as a general rule, applicable to regions where farms are based on the dung of animals, it is evident enough that the prices paid for artificial fertilizers must be intimately related to the value of farm-manure, and it may even be said that in the last analysis these prices must depend upon the cost of farm-manure. But the value put upon farm-manure is a matter of intangible opinion, rather than a formulated fact. It rests on the common consent of farmers the world over, and must be based ultimately on the gains which are got by using farm-manure, just as the prices paid for artificial fertilizers must depend finally on the benefits obtained when these fertilizers are used to replace farm-manure. This opinion of the farmers is supported by the experience of ages and by innumerable estimates of the values of the returns got by using farm-manure on all sorts of soils and under the most varied conditions as to crops and climates; and no matter how much the experience of any one man or collection of men may be obscured by varying seasons, or by any other of a thousand accidental causes of disturbance, the ultimate truths remain that farmers have arrived at a tolerably definite opinion as to the value of dung, and that this opinion is valid and real in every sense of the word, although it is somewhat vague.

How to Estimate Value of Manure.

In endeavoring to give precision to the foregoing general idea, two different methods of procedure have been resorted to: 1st, efforts have been made to determine experimentally in the field, under clean conditions, how large an area of wheat (or other crop) can be counted upon as a constant and legitimate gain from the use of a definite quantity of manure. And 2d, pains have been taken to determine the actual cost of producing manure at any given farm. The first of these methods has been found to be much more difficult than the second, because of our inability justly to allow for the peculiarities of a soil which depend on its mechanical texture and upon varying amounts of moisture held by the soil, or according as the original or natural strength of the land is large or small, and as unexpended balances from previous manurings are, or are not, contained in it.

It is true indeed that highly interesting experiments have been made in this way, and an account of some of them will be found at the end of this chapter. But for the generality of cases, the best way of estimating the price of manure will be to observe carefully the cost of making it at each particular farm; or, if the running expenses of his stable are already familiar, the farmer can calculate the cost of buying new quantities of food wherewith to keep more cattle, and he can thus determine what will be the cost of the fertilizing constituents in the manure. With the definite standard of value thus obtained, the prices of the commercial fertilizers may readily be contrasted. But it must be remembered, as was suggested long ago by Lawes, that the question whether the farmer shall keep more stock or buy artificial fertilizers is largely a question of capital. "It would require five times as much capital to produce the same amount of grain by means of stock as could be produced by artificial manures."

Considered as a whole, manure can undoubtedly be made at the farm in most localities much more cheaply than a mixture of its constituents could be compounded from purchased materials. But, as has been shown already, whenever occasion requires that a special manure (whether nitrogenous, phosphatic, or potassic) shall be used on a particular crop, it will ordinarily be cheaper to buy and use such special fertilizer as a reinforcement, than to apply enough farmyard-manure to supply the needed material. The conclusion being that, almost always, artificial fertilizers should

be used in conjunction with moderate doses of farmyard-manure to supplement its deficiencies.

According to Voelcker's analysis of farmyard-manure three months rotted, there is contained in a ton of it 24 lb. of potash, 6 lb. of phosphoric acid, and 15 lb. of nitrogen, and if 5 cents a pound be allowed for the potash and phosphoric acid, and no more than 10 cents a pound for the nitrogen, the ton of manure will be worth at least $3.00, and a cord (taken as weighing 3½ tons) would be worth $10.50. If 15 cents be allowed for the pound of nitrogen in rotted stable-manure, then the ton would be worth $3.75, and 3½ tons $13. But the cost of making and distributing manure on most farms is notoriously less than either of these figures. Perhaps half the sum last named would be a liberal estimate.

In 1841 Boussingault and Payen stated that the cost of farmyard-manure may be estimated at from $1.00 to $1.36 the ton, or even as high as $1.80, according to local circumstances; and, within a few years, another French writer, Borel, has said that estimates as to the value of a ton of farmyard-manure range from $1.60 to $4.00. In 1842, Boussingault, Payen, and Gasparin told of manure, from stables of the horses and mules used by carters in the South of France, which was sold at the "ordinary and fixed price" of $2.36 the ton. This manure gave the farmers a good profit when applied to irrigated land, but hardly paid for itself on dry sandy soils. In 1873, Petermann in Belgium computed that the cost of producing cow-manure at a particular farm, cited by him, was $2.10 the ton.

Each farmer must, of course, consider for himself, as a secondary question, the cost of hauling and distributing the heavy and bulky manure, and of working it into the land, as compared with the expense of transporting and handling the concentrated fertilizers.

Gasparin long ago gave the following 8 examples of the cost of obtaining manure from different kinds of animals in southeastern France:—

I. In the case of a flock of 100 sheep on the very poor pasturage of wastes (Landes) in Vaucluse, there was

Expended:		Received:	
For pasturage	$40.00		
" 5.5 tons of straw	28.00	100 fleeces, of 4.4 lb.	$40.00
" 110 lb. of salt	2.60	Sale of sheep	16.00
Shepherd boy and for shearing	39.20		
Depreciation of buildings and stock,			$56.00

interest, etc.	57.20	50 tons of manure	111.00
	$167.00		$167.00

In this case the manure cost $2.22 per ton.

II. In the case of a flock of 1,000 ewes kept in the neighborhood of Arles, in the year 1823, there was

Expended:		Received:	
For summer mountain pasturage and road expenses	$400.00	700 lambs	$1,120.00
For winter pasturage on rich marshes and plains	600.00	1,000 fleeces of 5.5 lb. etc.	650.00
For shepherds, shearing and sundries	530.00	To say nothing of milk eaten by the shepherds.	
			$1,770.00
Interest and depreciation ($\frac{1}{10}$)	320.00	33 tons of manure	80.00
	$1,850.00		$1,850.00

In this instance, where the animals were kept most of the time in their pastures, comparatively little manure was obtained; the cost of it was $2.42 the ton.

III. At a stable of 200 large milch ewes, at Tarascon, there was

Expended:		Received:	
For 38 tons of lucern	$315.20	160 spring lambs	$240.80
For 4.6 " cheap hay	25.20	28 new ewes, for stock	29.60
For 33 " straw for bedding	162.00	200 fleeces	120.00
For pasturage in stubble-fields	160.00	Wool of 28 lambs	4.20
For lucern aftermath, and pasturage on young barley	26.40	Merchantable milk	80.00
For shepherd, helper and shearing	164.00		$474.60
Interest and maintenance	154.00	220 tons of manure	532.20
	$1,006.80		$1,006.80

Here again the manure is reckoned at $2.42 the ton, which was almost the same price ($2.36) that was paid for manure at that time and place.

IV. In the case of 100 fatting sheep, there was

Expended:		Received:	
For autumn pasturage	$40.00	Increase in value	$200.00
For 440 lb. of fodder per head	160.00	50 tons of manure	42.00
Attendance during 5 months	42.00		
	$242.00		$242.00

In this case the profit from the fattening was so large that the ton of manure cost only $0.84.

V. At a stable of 35 cows in the Department of Ain, there was

Expended per cow:		Each cow yielded:	
For fodder and straw	$18.80	967 quarts of milk, which was made into cheese,	$18.61
For attendance, cheese-making, etc.	6.91	Calves	1.00
Interest and maintenance	3.26	Labor	3.50
	$28.97		$23.11
		5.6 tons of manure	5.86
			$28.97

Cost of the manure, $1.05 the ton.

VI. At a stable of fatting oxen in the Department of Gard, there was

Expended per ox:		Each ox yielded:	
Paid for the animal	$26.40	770 lb. meat at $0.0727 cents per lb.	$56.00
Paid for fodder (chiefly hay) . . .	21.60		
Paid for attendance	1.50		
	$49.50		
Profit	6.50		
	$56.00		

Here the manure was a free gift, i. e. "given to boot," though as Gasparin remarks, skill and knowledge are needed in order to get profit from fattening stock.

VII. In a stye of fatting hogs, the

Cost per hog was:		Each hog produced:	
Price paid for the hog	$6.00	225 lb. of pork at $0.08+ per lb.	$18.31
257 lb. of potatoes	1.50		
1.7 bushels of beans	1.78		
1.7 " acorns	1.20		
0.9 " maize	1.37		
4 lb. of bran per diem during a part of the time	2.28		
	$14.13		
Profit	4.18		
	$18.31		

Here again 1.65 tons of manure were obtained gratuitously.

VIII. Two work horses at Tarascon

Consumed:		Yielded:	
2 tons of lucern	$11.66	194 days' work at $0.30 .	$58.20
7 " rough hay	26.40	33 tons of farm-manure sold at $1.81 the ton .	$59.73
5.5 " straw	14.60		$117.93
2 " reeds, for bedding . . .	4.00		
23 bushels of oats	9.60		
Interest and depreciation	11.00		
Shoeing, etc..	3.40		
	$80.66		
Profit	37.27		
	$117.93		

Gasparin remarks further, of his time and locality, that—in addition to the value of the labor of the animals—either

A carter's horse Consuming	At a cost	Or a farm horse Consuming	At a cost	
11 lb. oats	$0.18	33 lb. hay	$0.18	Will produce 88 lb. of manure, that could have been sold at $0.10.
22 " hay	0.20	11 " straw . . .	0.02	
11 " straw . . .	0.02			
44 " in all.	$0.40	44	$0.20	

Dettweiler has computed, in the following terms, the cost of producing cow-manure per head and per year, at four different farms in Germany, from which the milk is sold as such. No. V. of the table is another wholly independent calculation by a German farmer named Herter.

	I.	II.	III.	IV.	V.
Cost of fodder consumed	$138	$136	$153	$149	$66
Cost of care and attendance	11	11	11	11	10
Cost of bedding, i. e. 1.33 tons of straw per year and head	8	8	8	8	5
Depreciation of the animal, etc.	8	8	12	8	
Sum of these expenses	$165	$163	$184	$176	$81
Income from sale of milk	154	149	179	148	66
Cost of manure of 1 cow for one year	$11	$14	$5	$28	$15

He reckons that, bedding included, one cow will produce 14 tons of manure in a year. Herter reckons that each of his cows produces 13 tons of manure in a year, at a cost of $1.15 the short ton, and that it costs him about 17 cents a ton to haul out the manure to the fields and spread it.

Bismarck has published a somewhat similar calculation relating to a stable of 70 head of cows in Pomerania. These cows were fed upon potato-slop and straw, with very small additions of hay and grain-refuse, so that the cost for food amounted to but little more than $52 per head and per year, while the cost of care and attendance, interest, and depreciation of buildings, was reckoned at $8 per head. The total income from sale of milk and other products was $3,062 per year, and the cost of keeping the animals was $4,250. Hence the manure cost $1,188, or nearly $17 for each of the cows. This manure was applied to 170 acres of land, so that each acre got $7 worth of it, no account being taken of the cost of carting and distributing the material.

Cost of Manure from Root-feeding or Grain-feeding.

Vallentine, in England, has calculated the cost of producing farm-manure by fatting cattle, according as the animals were fed on roots and straw, or on purchased food. On his farm of 240 acres of arable land, 60 acres were devoted to swedes and mangolds; the average yield of roots, taking one year with another, being no more than 10 tons to the acre. During several winters about 60 head of cattle were fed in open yards, and each of them consumed about 1.5 cwt. of roots per diem. All the straw which the farm produced was consumed as food and litter, but the animals got neither clover nor hay. Each of these cattle made about half a ton of dung per week, and the rate of increase of meat (carcase weight) was about 6 lb. per week. During 20 weeks' feeding, the money return ranged from $1 to $1.50 per week, according to the progress of the animals and the price of meat, and in all some 600 long tons of manure were produced. The cost of the manure thus obtained from roots and straw will appear from

the following table. For the sake of comparison, there is given also in the table an estimate of the cost of fattening cattle on hay and roots, with addition of purchased foods, viz. cotton-seed-meal, linseed-cake, and Indian meal. In this case, where each animal is supposed to get 0.5 cwt. of roots per diem, instead of 1.5 cwt. as before, three times as many cattle (i. e. 180) would be required to consume the roots.

Per head and per week:

When fed on roots and straw.	
10.5 cwt. roots per week, at $2.00 per long ton	$1.05
3 cwt. straw, as fodder and litter, at $2.40 the ton	0.37
Interest, attendance, etc.	0.25
Sum of the weekly expenses	$1.67
Income from meat, 6 lb. at 16 cts.	0.96
10 cwt. of manure, cost	0.71
Cost of 1 long ton of the manure	1.42

When fed on hay, roots, oil-cake, etc.	
8 lb. oil-cake and meal per diem, or 0.5 cwt. per week, at $35.00 the ton	$0.87
1 cwt. clover or hay, at $17.40 the ton	0.87
1 cwt. straw litter	0.13
3.5 cwt. roots, at $2.00 the ton	0.38
Interest, attendance, etc.	0.25
Sum of weekly expenses	$2.50
Income from 8 lb. meat at 16 cts.	1.28
5 cwt. of manure (made in box-stalls)	1.22
Cost of 1 ton of the manure	4.88

It is to be noticed that the 900 long tons of manure obtained in 20 weeks from 180 head of cattle, stall-fed, in this way would cost nearly $4,400, while the 600 tons of manure from the 60 cattle fed on roots and straw would cost only about $850, i. e. $3,550 less than the sum expended in order to obtain the rich manure. As Vallentine urges, it is safe to say that $1,000 expended in buying artificial fertilizers wherewith to reinforce the poor manure obtained from roots and straw, would usually bring crops as good as those got with the richer dung of the stall-fed cattle, and would yield more profit to the farmer also.

The conclusion would seem to be that, in the present condition of agriculture, few farmers can afford to fatten many cattle on oil-cake, as a means of enriching the land. The German plan of obtaining manure from milch cows fed on slop (or ensilage), properly balanced or reinforced with other kinds of foods, seems to be much more economical than the English method of fattening steers on roots and oil-cake.

Professor Wrightson noted instances in Austria and in Hungary, where farmers estimated that the dung produced by oxen fattening in stalls cost them, respectively, 2.5 and 5 cents per diem, or at the rate of $9.12 and $18.25 per annum.

Proposals for Mixtures.

After all that has been said in relation to the superiority of dung and urine, it is still true — making due allowance for this superiority — that some useful suggestions, both for using the artificial fertilizers in conjunction with farmyard-manure, and for using the artificial fertilizers by themselves as substitutes for farmyard-manure, or in competition with it, may be got by writing out schemes such as the examples given in the following table, in which the fertilizers or mixtures enumerated contain the stated number of pounds of plant-food.

	Nitrogen.	Phosph. Acid.	Potash.
8 cords of excellent farmyard-manure, 3 months rotted, that weighs 3½ tons to the cord	120	168	192
4 cords of such manure and 350 lb. of a superphosphate of 12% P_2O_5 (a mixture used for turnips)	60	126	96
4 cords of the farmyard-manure and 400 lb. fish-scrap (of 7% N and 6½% P_2O_5)	88	110	96
4 cords of the farmyard-manure and 200 lb. Peru guano (of 8% N, 14% P_2O_5, and 3% K_2O)	76	112	102
2 cords of such manure and 1,000 lb. cotton-seed-meal (of 7% N, 2⅔% P_2O_5, and 1½% K_2O)	100	70	63
A mixture of 1,000 lb. cotton-seed-meal, 500 lb. of superphosphate, and 200 lb. of kainit	70	87	39
A mixture of 2,000 lb. cotton-seed-meal and 800 lb. cotton-hull ashes	140	119	200
A mixture of 2,000 lb. cotton-seed-meal and 650 lb. of the double sulphate of potash and magnesia*	140	55	200
A mixture of 500 lb. of bone-meal (of 4% N and 23% P_2O_5) and 30 bushels wood-ashes at 48 lb. (of 2% P_2O_5 and 8½% K_2O)	20	154	122
A mixture of 30 bushels wood-ashes and 1,000 lb. fish-scrap	70	94	122
A mixture of 30 bushels wood-ashes and 300 lb. nitrate of soda	46	29	122
A mixture of 30 bushels wood-ashes and 1,000 lb. cotton-seed-meal	70	57	137
A mixture of 1,000 lb. fish-scrap and 200 lb. muriate of potash of 80%	70	65	100
A mixture of 800 lb. cotton-seed-meal, 400 lb. bone-meal, and 200 lb. muriate of potash	72	114	112
A mixture of 600 lb. bone-meal, 100 lb. muriate of potash, and 200 lb. nitrate of soda	55	138	50
A mixture of 1,000 lb. fish-scrap and 800 lb. kainit of 12% K_2O	70	65	96
A mixture of 200 lb. superphosphate of 12% soluble P_2O_5, 1,000 lb. fish-scrap, and 200 lb. muriate of potash	70	89	100

* On a non-calcareous soil, it might be well to add 200 or 300 lb. of lime to ensure a mild alkaline reaction favorable for the nitrification of the cotton-seed meal. (S. W. Johnson.)

A mixture of 300 lb. superphosphate of 12%, 1,000 lb. cotton-seed-meal, and 100 lb. muriate of potash	70	64	65
A mixture of 400 lb. superphosphate of 12%, 300 lb. nitrate of soda, and 800 lb. kainit of 12% K_2O . .	46	48	96
A mixture (suggested by some of those used by Lawes and Gilbert) of 200 lb. bone-ash (of 32% P_2O_5) that has been treated with acid, 300 lb. sulphate of ammonia, and 500 lb. kainit	60	64	60
A mixture of 500 lb. superphosphate of 12% soluble phosphoric acid and 25 bushels wood-ashes . . .	...	84	102

It should be distinctly understood, however, that such schemes can do no more than indicate the amounts of the more important kinds of plant-foods which are contained in the mixtures enumerated. They do not teach that one or another of the mixtures is as good as farmyard-manure. Information such as that can only be gained by trial of the mixtures upon the particular field which it is proposed to cultivate.

It will be remembered withal, that the artificial fertilizers are often applied with reference to but a single crop, while it is commonly expected that the influence of a dressing of farmyard-manure shall be felt for several years; and that no inconsiderable proportion of the useful effect of the manure is to be attributed to the influence which it exerts for improving the capillary condition of the soil and promoting the growth therein of useful micro-organisms; that is to say, to its bringing the land into a good condition of fermentation.

In drawing up any such schemes as the foregoing, the farmer will naturally lean towards the fertilizers most readily procurable in his vicinity, and to the kinds of plant-food best suited to the crops he means to cultivate, and on good land he will generally do well to apply the fertilizers liberally. It is a common saying in the rich sugar-beet districts of central Germany, where the land is measured by Morgen (0.631 acre), that "it is the second cwt. of an artificial fertilizer which really does the work."

Practical Suggestions for Mixtures.

Another way of formulating the quantities of fertilizers to be given to a crop is suggested by the following "general rule," proposed by Heiden as applicable for manuring potatoes either on heavy or on light land. For each pound of nitrogen applied to the land, from 3 to 5 lb. of phosphoric acid should be given, according as more or less time has elapsed since the land was dressed with dung. The amount of nitrogen to be applied to an acre may

range from 12 to 25 lb., and that of phosphoric acid from 65 to 75 lb. In case potash is needed, he recommends that 800 or 1,000 lb. of the double sulphate of potash and magnesia should be used.

Schultz recommends for fallow and preparatory crops on poor, old, dry, sandy soils, which have been marled, 35 lb. phosphoric acid and 70 lb. potash to the acre, to be applied in the form of a plain superphosphate, or of bone-meal, and of kainit (520 lb. to the acre). He finds no profit on such land from buying nitrogenous artificial fertilizers. For reclaimed moors, rich in nitrogenous humus, Rimpau has recommended 50 lb. soluble phosphoric acid to the English acre, and from 75 to 100 lb. of potash, in the form of kainit. When used in conjunction with stable-manure, he employs one-half the above quantities of phosphoric acid and potash, together with 3 or 4 tons of the manure, to the acre. In case the manure is used without any addition of artificials, he applies from 5 to 9 tons of it to the acre, or say 7 short tons. Doubtless, for moorland use, the cheap phosphatic slag is to be preferred in many instances to a superphosphate as here recommended.

In field experiments with potatoes, made in several localities, Wildt got satisfactory results by applying superphosphate of lime and sulphate of ammonia at the rates of 35 lb. soluble phosphoric acid and 17 lb. nitrogen to the acre. The most profitable crops of all, however, were got by means of half-dressings of farmyard-manure reinforced with 35 lb. soluble phosphoric acid. With sugar-beets, the best results were obtained on using 70 lb. soluble phosphoric acid and 34 lb. nitrogen to the acre.

Lawes's Suggestions for Mixtures.

Many years ago, some practical suggestions were published by Lawes as to the quantities of fertilizers that can be used with advantage. They were based on results obtained in the field experiments of Gilbert and himself, and upon observations of the practice of other English farmers. For wheat he recommended that farmyard-manure should be applied directly, in case the land was light; but on heavy land he would have the manure applied to mangolds, and, as a manuring for the wheat that followed these roots, he would strew and harrow in, just before seeding, from 200 to 300 lb. of guano to the acre. Many English farmers, he says, have found their advantage in adding to the guano twice its weight of common salt.

For barley, grown after wheat, he recommends that there should be applied in the spring from 40 to 50 lb. of ammonia to the acre, or an equivalent amount of nitrogen in the form of nitrate of soda or oil-cake. From 1.5 to 2 cwt. of sulphate of ammonia, or 1.75 to 2.25 cwt. of nitrate of soda, or 6 to 8 cwt. of rape-cake, would meet these requirements. And, in addition to the nitrogen, he would use 2 or 3 cwt. of a plain superphosphate. An earlier recommendation for barley or oats, in case either of these crops should follow wheat, in a rotation, was 200 lb. of guano or of nitrate of soda, and 200 lb. of superphosphate, to be harrowed in as before; but in case the crops followed turnips or mangolds, which had been dressed with dung, half the stated quantities of the artificial fertilizers would be sufficient, because of the unexpended manure already in the land. In case any grain-crop should seem to be in need of a top-dressing in late spring, nitrate of soda, applied at the rate of 100 to 125 lb. to the acre, may be commended.

Mangolds are well suited by liberal dressings of farmyard-manure, especially when the land is heavy, the manure to be applied at the rate of from 15 to 20 tons to the acre, together with 200 or 300 lb. of guano mixed with 400 to 600 lb. of common salt [or, better, with Stassfurt muriate (?)]. Voelcker commends, for mangolds on light land, a mixture of 3 cwt. of plain superphosphate, 2 cwt. of kainit, and 1 cwt. of nitrate of soda per acre as an economical and beneficial manure, and on another occasion he remarked that a dressing of 3 cwt. of Peruvian guano, 2 cwt. of superphosphate, 1.5 cwt. of nitrate of soda, and 2 cwt. of common salt, is considered a somewhat heavy but a well-paying manure. He mentions as a common English dressing for barley, 2 or 3 cwt. of superphosphate and from 1.5 to 2 cwt. of nitrate of soda.

Fertilizers for Potatoes.

For potatoes, Lawes did not commend the usual method of dressing heavily with dung, but recommended that the dung should be applied to a previous crop, and that the potatoes should receive in their turn 150 to 200 lb. of guano, together with as much superphosphate. In his experiments on the continuous growing of potatoes, there was obtained during the first 4 years, on land manured with nitrate of soda, superphosphate of lime and potash-salt, crops amounting to 7 long tons and 6 cwt.

per year and per acre on the average, while the crops obtained by using farmyard-manure in conjunction with nitrate of soda and superphosphate of lime were on the average 7 tons and 2 cwt. during 6 years. From farmyard manure and superphosphate (without the nitrate) the annual yield was 5 tons and 12 cwt. during 6 years; and from farmyard-manure alone 5 tons and 5 cwt. were harvested annually during six years.

It was noticed as somewhat remarkable that, taking the full term of 12 years during which the trials lasted, on neither plot which received farmyard-manure, not even where it was applied each year of the twelve, was there so much produce as on the artificially manured plots which got both nitrogenous and mineral fertilizers. Indeed, not even where nitrate of soda was applied in addition to farmyard-manure during the first 6 years did the average produce of the 12 years amount to 6 tons of tubers.

It was found, moreover, that only a small proportion of the nitrogen of the farmyard-manure was taken up in the year of its application, and the results of the experiment seemed to indicate that the potato is able to avail itself of a less proportion of the nitrogen in this manure than any other farm crop. Yet, in ordinary practice, farmyard-manure is not only largely relied upon for potatoes, but is often applied in larger quantities for them than for any other crop. It is probable, as Lawes and Gilbert urge with no little justice, that a part of the utility of the manure may depend on its influence to improve the mechanical condition of the soil, and on the increased temperature of the surface soil due to the fermentation of the organic matter of the manure.

Voelcker found in numerous field experiments that large crops of potatoes can be obtained on light sandy soils by means of a mixture of 4 cwt. of plain rock superphosphate, 2 cwt. of crude potash salts and 2 cwt. of sulphate of ammonia, or of nitrate of soda. In repeated instances the application of this mixture to light land gave as large crops as were got by means of 20 tons of well rotted farmyard-manure. But on heavier land the use of artificial fertilizers gave much less favorable results. On good clay loams, for example, the mixed fertilizers above mentioned were far less useful than on sandy soils. They gave crops that were only one-half as large as those got by means of 20 tons of farm-manure. It was noticed, moreover, that on stiffish soils containing a fair proportion of clay neither sulphate of ammonia

nor nitrate of soda were as useful in a potato manure as they were on light, sandy land.

Fertilizers for Hay-fields.

For hay-fields, a very generally useful top-dressing may be made of 3 parts Peruvian guano, 1 part nitrate of soda, and 1 part sulphate of ammonia. This mixture may be strewn early in the spring at the rate of 2 to 2.5 cwt. to the acre. If it were economically possible to apply this mixture annually, and 10 or 12 tons of poor rotten dung at intervals of 4 or 5 years, good crops of hay might be mown every year without injury to the land. Peruvian guano, when used alone, may be applied at the rate of 1.5 to 2.5 cwt. to the acre; nitrate of soda alone, or sulphate of ammonia alone, at the rate of 1.5 to 2 cwt. Other mixtures which have been used at one time or another in England, on permanent grass-land, are: From 2 to 2.5 cwt. of plain superphosphate, 3 cwt. of kainit, and 1 to 1.25 cwt. of nitrate of soda to the acre; and 3 cwt. of bone phosphate, 1 cwt. of kainit, and 0.5 cwt. of nitrate of soda, or of a mixture of the nitrate and sulphate of ammonia, to be applied early in the spring.

For hay-fields, Lawes recommends dressings of well rotted farmyard-manure every 4 or 5 years. He urges that they should not be manured exclusively with artificial fertilizers; though, as his own experiments show, it may occasionally be well to reinforce the dung with sulphate of ammonia. On another occasion he says, "I am disposed to think a dressing of dung once in 5 years and 2 cwt. of nitrate of soda the other 4, is about as good an application as can be used."

In England by far the largest quantity of commercial fertilizers are used upon root crops. In the words of Voelcker, "there are many parts of England where turnips and swedes are grown with no other manure than plain mineral superphosphate applied at the rate of 3 or 4 cwt. to the acre. On cold clay soils, in a fair agricultural condition, it has been found that 3 cwt. of such a superphosphate will produce at least as heavy a crop of swedes and turnips as a manure containing ammonia or nitrogenous organic matter, in addition to soluble phosphate of lime. On light land, however, the use of a purely phosphatic manure cannot be relied upon for producing a good crop of roots. On such land artificial manures are seldom used alone, but usually in conjunction with half a dressing of common dung. Dissolved bones, dissolved Peruvian guano, or compound artificial manures containing 2 or 3% of ammonia, are greatly preferable to mineral superphosphate as manure for root crops on light land and on loamy soils out of condition."

Fertilizers for Hops.

According to Lawes, hops need to be dressed abundantly with animal or vegetable matters that are not too forcing, such, for example, as woollen rags, wool-dust, horn-meal, rape-cake, or hide-scraps; and it is only in conjunction with such things that the concentrated fertilizers, particularly guano, have given satisfactory results in respect to this crop. All this consists with the dictum of Tusser that hops hate gravel and sand, but thrive in rotten mould.

Marshall reported in 1790 that in the County Kent "woollen rags have of late years been a favorite and are found to be a powerful manure for hops. Pond-mud also has lately been much valued as a manure for this crop. On the absorbent, non-calcareous soils of the Tunbridge quarter, lime has been found of particular efficacy. . . . But the long established custom is to manure hops with compost made from the dung of cattle that have been fed with oil-cake. For hops, raw dung is seldom used. It is chiefly or wholly made into compost with mud or mould of any kind that can be collected, as the soil of lanes and waste places."

For cabbages, Dyer has recommended the application, at seed time, of 4 cwt. of superphosphate, in case the soil is fairly calcareous, or, if not, then 3 cwt. of superphosphate mixed with bone-meal or ground phosphate rock. After the plants have been thinned out, a top-dressing of 2 cwt. nitrate of soda and 3 cwt. of salt per acre may be applied. As alternatives, he suggests 2.5 cwt. of Peruvian guano (of 8 or 9 % ammonia) at seed-time, together with 2 cwt. of salt; or a similar quantity of lower grade guano at seed time, to be followed by a top-dressing of 1 cwt. nitrate of soda and 3 cwt. of salt.

Fertilizers for Tobacco.

For tobacco, Nessler directs that on suitable land there may be applied, per acre, in the autumn, 100 lb. of superphosphate of 16 %, together with 250 lb. of purified double sulphate of potash and magnesia (which should not contain more than 3 % of chlorine). Next spring, from 125 to 175 lb. of nitrate of soda may be applied in addition. Or, in case the land is already in high condition, it may be dressed as early as possible in the spring with 125 to 175 lb. of the purified double sulphate of magnesia and potash, 75 lb. of the superphosphate, and from 125 to 175 lb. of nitrate of soda. A solution of this mixture, prepared by mixing

1 lb. of it with 13 gallons of water, may be used also for watering the plants in early summer. More recently, A. Mayer has urged that nitrate of potash and carbonate of potash are better for tobacco than the sulphate. He holds that sulphates as well as chlorides are prejudicial to the combustibility of tobacco, and that they should be avoided. In this point of view, even those phosphates which contain the smallest proportion of sulphates (gypsum) are to be preferred to ordinary superphosphate by the tobacco grower.

In consonance with practical experience, Mayer maintains that, for Holland at least, farmyard-manure makes the best basis for tobacco, even on soils rich in humus. He finds that the manure had better be applied in the autumn, and re-enforced with nitrate of soda in the spring. Naturally, he admits that, when not enough stable-manure is to be had, artificials may be used to supplement it or to replace it. Generally speaking, night-soil should be avoided by the tobacco grower.

Gasparin's Field Experiments to test the value of Manure.

In order to exclude, in so far as might be possible, all influences due to previous manurings or to the natural fertility of the soil, Gasparin chose for his experiments a tract of new, uncultivated land near the river Durance, in Southeastern France, and, after having applied to it definite quantities of manure, he proceeded to irrigate the crops in such manner that they were kept constantly under conditions favorable for maximum growth, and for the best possible utilization of the goodness of the manure. The soil experimented upon was a hardly coherent river-sand, — almost absolutely free from organic or nitrogenous matter, — the poverty of which was attested by the sparse vegetation natural to it. Doubtless, this sand had formerly been very thoroughly leached by the currents of water which transported it to its present position. "No farmer could have dared to sow seed upon this land in the hope of reproducing that seed," without manure.

In the course of the three years devoted to the experiment, there was applied to 2.22 acres of this land 23 tons (of 2,000 lb. each) of manure from the stable of an inn where carters' horses were kept. This manure contained 61 % of water and 0.8 % of nitrogen. The weight of seed-grain sown during the three years was 317 lb., while there was harvested 3,146 lb. of wheat-grain, beside a variety of stolen crops to be mentioned directly. On the assumption that by means of irrigation alone it would have been possible to reproduce the seed that was sown, there will remain to be credited to the manure 2,829 lb. of wheat, worth, at the time and place of the experiment, $70.74. The straw, which was assumed to weigh about twice as much as the grain, would on most farms naturally be used for the production of a new stock of manure, and the value of it for this purpose might well be subtracted from the cost of the manure employed

in the experiment. In this particular experiment, Gasparin considered it equal to 1,718 lb. of the manure. After the wheat, which was always the principal crop, stolen crops, either of potatoes, beans, or millet, were grown to the value of $38.66, after subtracting the cost of the seeds sown, beside straw and haulm, which were reckoned to be equal to 922 lb. of the manure. Altogether there was produced $109.40 ($70.74 + $38.66) worth of crops from 21.7 tons of manure (i. e. 23 tons less 1.3 tons credited to the straw of the crops). Hence the value of a ton of the manure was $5. Or, as Gasparin put it, the price of 100 kilos of the manure was equivalent to the price of 10 kilos of wheat. It will be noticed that in presenting the results of this experiment, the cost of tilling the land and of sowing, harvesting, and threshing the grain, etc., have purposely been omitted, because these items are necessarily different in different places, and must be considered by themselves in any given locality.

On contrasting the above results with the conclusions of other farmers who had made observations in a similar though probably a less accurate way, Gasparin noted that 100 kilos of manure would be equivalent to 7.6 kilos of wheat according to Thaer, to 8.2 kilos of wheat according to Burger, and to 9.5 kilos according to Kressig.

On dry soils it is much less easy to determine the value of manure, for the crop will depend upon how much rain happens to fall, and the only way of arriving at a general conclusion is to collect statistics during many years in each locality. In Southeastern France, for example, where much of the land is so dry that no more than 10% of moisture can be found in it at the depth of a foot after a week of dry weather in August, manure has comparatively little effect on crops in dry years, and much of the goodness of it goes to waste by way of decomposition. When a season happens to be specially dry, such land often yields smaller crops the year manure is applied to it than are obtained previously and subsequently when the weather is less unfavorable. On contrasting the crops of wheat obtained with and without manure during terms of ten years on several estates situated on such land, Gasparin found that 100 kilos of manure produced 3.4 kilos of wheat on the average. This result made the manure worth $1.74 the ton, which was less than the current price of manure in that locality.

As regards other crops than wheat, Gasparin concluded from his own experiments and from the experience of farmers in the North of France, that on soils adequately moistened which contained no unexpended residues of old manurings, 100 kilos of manure will bring 165 kilos of sugar-beets; and, allowing for the fodder value of the press-cake, he concluded that the value of the manure was in this case $5.18 the ton, which is remarkably close to the value found in the case of watered wheat. He remarks that larger yields of beets than he got are often obtained on soils naturally fertile and on soils previously charged with manure. On dry soils, as he held, manure produces, on the average, only about half as large a beet-crop as on moist land, and the value of the manure amounts to no more than $2.63 the ton, which is a trifle larger, nevertheless, than the price at

which manure was sold there. It will be noticed that this result is decidedly better than that got from wheat on dry land, and the reason of the difference is that in years when rains fall seasonably beets do very well on such land.

A permanent mowing field, which had previously gradually been brought up to its maximum fertility, was top-dressed in such manner that 32 tons of manure per annum gave, on the average of years, 16.8 tons of hay, worth $10.90 the ton. In other words, one ton of the manure brought rather more than half a ton of hay, worth $5.63.

Similar experiments were made by Gasparin on several other crops, and all his results are given in the following table. The current price at which stable-manure was sold at the time and locality was $2.36 the ton.

The gain got from one ton of the manure by growing crops of	On moist or moistened soils, was	On dry soils, was
Madder	$9.27	$4.00
Olive-trees	...	8.72
Grape-vines	...	6.55
Hemp	6.72	...
Permanent hay-field	5.63	...
Sugar-beets	5.18	2.63
Wheat	5.00	1.74
Colza	3.72	...

These results not only indicate the advantages derivable from irrigation, but they show very clearly how, in hot countries, profit may be got from deep-rooted, long-lived plants such as vines and olive-trees, which can find moisture in the subsoil, where most annual crops would yield nothing, or next to nothing. It is to be noted as one merit of vines and olives in hot countries, that, barring accidents, such as disease, the average profit got from them in a term of years is tolerably constant and certain, since any diminution of crop due to an exceptionally dry year will be compensated for by the increase obtained in specially good years. Manifestly such plants as these will be owned by capitalists, and not by cultivators who are living from hand to mouth.

Artificials contain no Spores of Fungi, Eggs of Insects, or Seeds of Weeds.

It has been insisted already that it is comparatively easy to keep land clean and free from weeds when, instead of farm-manure, it is fertilized with chemicals, or with sea-manure, or the ashes of dung; but the same remark may be made in respect to some insects and to certain fungi, injurious to vegetation, the spores of which are capable of passing undigested through the intestines of animals, and are carried to the fields with the dung. One noteworthy example of this fact is seen in the case of potatoes, which are apt to be "scabby" when the land on which they are grown has been dressed with the fresh manure of animals to which scabby potatoes have been fed. According to Terry, this

trouble will occur, no matter whether the manure has been applied in the autumn, the winter, or the spring before the potatoes are planted; and it has been shown by the experiments of Thaxter that the manure of horses which had been fed with scabby potatoes was badly infested with the scab-fungus. He found, too, that the scab-fungus grows luxuriantly in decoctions of horse- or cow-dung which have been seeded with it. Hence the advice that scabby potatoes should neither be fed to animals nor be thrown upon the manure-heap, unless, indeed, they have been thoroughly cooked.

"In general," according to Thaxter, "any fertilizer is to be preferred to barnyard-manure for potatoes, whether the stock has been fed with diseased potatoes or not," though he and others have noticed that the presence of carbonate of lime in the soil favors the development of the scab fungus. Terry has urged that on good land the potato scab may be avoided by applying fresh farmyard-manure to a clover-sod, which is to be ploughed under subsequently for Indian corn. By sowing rye under the corn in the autumn, and ploughing in the rye-sod in the spring, he has been able to put the land into fit condition for growing clean potatoes. As has been said already, the seed potatoes may be disinfected by means of corrosive sublimate.

CHAPTER XXIX.

THEORY OF THE ROTATION OF CROPS.

Beside tillage and the use of fertilizers, there are various other methods of increasing the yield of crops; and one of the most important of these methods is the growing of different kinds of plants from one year to another upon a given field, instead of taking one and the same kind of crop continually from the land, year after year. The experience of many generations of farmers has taught not only that some kinds of plants cannot well be grown continuously, and that some crops will not grow well after others, but that, strangely enough, some kinds of plants actually grow better immediately after the land has been occupied by certain other kinds.

When this "rotation of crops" was practised systematically and strennously, so to say, according to well-established rules and

customs, as was done formerly in many parts of Europe, the idea was to divide the farm into as many parts, or divisions, as there were kinds of crops to be grown, and to raise a different crop upon each division every year. Suppose, for example, the rotation were one of five years, the farm would be divided into five "shifts," as the English term is, and the crop of the present year — wheat, for example — would be grown upon division No. 1; next year it would be grown upon division No. 2, and so on; while the next crop in the series, whatever it might be, would follow the wheat. That is to say, this crop would be on division No. 5 this year, and on No. 1 next year. On the sixth year wheat would get back to division No. 1.

Practically, it should be said, the entire farm, if it were at all large, was seldom thus divided in gross for the purposes of rotation. On the contrary, the farm was first divided, according to the lay of the land and the character or quality of the soil, into several great sections, and each of these sections was divided in its turn into the separate fields, or shifts, just spoken of. By proceeding in this way, it was possible to distribute the crops to better advantage, and to have each of them represented every year upon different parts of the farm, so that, no matter what kind of weather might be vouchsafed, each crop would have opportunity to succeed somewhere upon the farm.

Peculiarities of Crops and Soils.

As a matter of course, the requirements of different kinds of soils and of crops had to be kept in view, and allowances were made for the peculiarities both of soils and of plants. There are comparatively few plants that can grow equally well on all kinds of soils. This fact is familiarly illustrated by the preferences shown by different species of weeds for one or another location. So, also, one of the most important items of skill in the practice of greenhouse gardening is the knowledge how to commingle different kinds of earths in such proportions that each and every variety of plant shall be potted in a soil perfectly well adapted to its own peculiar requirements. On this account the rotations on light and dry soils need to be arranged differently from those on stiff and moist land.

In regions favored with soils fit to bear wheat, it has always happened that the course of crops was arranged with a view to wheat-growing, while on poorer land rye was grown instead of the

wheat. So, too, in respect to spring-sown grain; if the land was proper for barley, barley was grown upon it in due course, whereas on soils not well suited to barley, oats were grown in its place. Flax and hemp had to be grown on good land in any event; and plants like sainfoin and lucern, which remain on the land for years, must needs be grown on deep soils that are not too stiff. It would be folly to try to grow them in unsuitable places.

In any given locality, each and every kind of land required its own particular course of rotation; but the ultimate result on farms everywhere was that every year just so many acres were laid down to wheat, to rye, to flax, to clover, or what not; and, taking one year with another, tolerably definite and determinate yields were to be expected from each of the crops, so that a constant number of cattle could always be kept, just so much manure be made, just so many products be sold, and just so much income be counted upon. All this tended, of course, to fixed and constant work and results, not to say to rigidity of method and action.

We have now to inquire why it was that the farmers took all this trouble; for, assuredly, it would seem to be more natural for them not to have tied themselves up in such complex arrangements, but to have grown their crops where they pleased and when they pleased.

Crops differ in Respect to Frugality and Hardihood.

Several of the more important facts which bear upon the theory of rotation may be enunciated as follows. Some kinds of plants require much less food than others. Or, rather, they can prosper when neither table nor larder is spread or filled, i. e. in situations where very little food is placed at their immediate disposal. Look at the cactuses of the desert, for example, and at the beach-grass that grows on drifting sand-dunes, and at the pitch-pine trees of the sand-hills of New England. When spurrey was sown upon poor sandy soils, on the Continent of Europe, to be ploughed under as a green manure for rye, it used to be said that it "lived upon air."

Good instances of plants whose habits are utterly unlike those of these hardy pioneers are to be seen in various ornamental trees which have been brought to this country from Europe, such as the horse-chestnut and the sycamore-maple (Acer pseudo-platanus). Both these trees thrive in cultivation in the vicinity of

Boston, and they seed freely; and when the seeds happen to fall upon rich land they germinate readily enough, and grow until the saplings are cut off by the gardener's hoe or the mower's scythe. Neither of these trees has become naturalized to the locality, although the horse-chestnut at least has been a favorite tree here during many generations. To all appearance, the trouble is that these particular trees require rich land when young, and that they cannot get started in life on poor soils, or in waste and neglected places. But there are several farm crops as fastidious as either of these trees. In the words of Jefferies, "Capricious as a woman, hops will only flourish here and there; they have the strongest likes and dislikes, and experience alone finds out what will suit them." In the temperate zone, at least, tobacco will not grow freely on poor land. Heavy dressings of manure are needed in order to get large crops of it.

Indeed, it is a practical rule, familiar to all farmers, that different kinds of plants differ widely as to their power of drawing food from one and the same soil. Compare, for example, the desert plants just spoken of with the ordinary plants of cultivation; or, among the agricultural plants, contrast buckwheat, rye, oats, or lupines, which will grow on extremely poor soils, with the crops that require richer feeding. Rye and buckwheat can be grown with profit, as may be seen every year in New England and in Northern New York, on soils where most other crops would starve, and it has long been customary in many localities to grow oats on those fields in the rotation which have been most exhausted by previous crops.

The Carrot is a Robust Plant.

It is said that carrots also differ widely from other root-crops, such as beets and turnips, in respect to their power of obtaining food. According to Way, the carrot consumes as much food, both mineral and vegetable, as either the beet or the turnip; but good crops of carrots can be grown without manure where turnips would inevitably fail. Carrots are in fact constantly grown in England without manure at all periods of rotations, and in all kinds of soils, provided they are deep enough. Not that the carrot is ungrateful for manure, but that, unlike the other root-crops, it can be grown without it. It is commonly taught, however, that carrots should not be dressed with fresh manure, lest they form forked roots, but with a well-rotted product; and this rule would

naturally tend to determine the position which the carrot-crop should occupy when grown in rotation with other plants. The habit of the carrot to grow "rooty" or "fangy" when dressed with fresh manure seems to be a fact of the same order as the rankness of growth of grain under similar conditions. It is well known that fresh manure is apt to cause wheat to run to leaf and sometimes to "stool" or "tiller" to an unprofitable degree. It would be of interest to determine whether an addition of common salt to the fresh manure might not check the irregular growth of the carrot, as it is known to hinder the leafy growth of wheat. In an old experiment by Sinclair, 40 long tons of carrots to the acre were got on manuring with a mixture of 6.5 bushels of soot and 6.5 bushels of salt, while no more than 23 tons of carrots to the acre were got from the unmanured land. One fact to be noted, of course, is that the carrot has particularly deep roots. Hard or stony soils are not suited to this plant, simply because of the mechanical obstructions to its growth which they interpose. But it is said that in good deep clayey loam the long tapering roots of carrots have been traced to a depth of ten feet and more.

Crops may consume Food at different Times.

Not only do different crops require different amounts of food in order to come to maturity, but since the life of some kinds of plants is shorter than that of others, one kind of crop may require a richer soil than the other kind; not because it removes more food from the land in the aggregate, but because it requires more food in a given time.

Leguminous Crops obtain Nitrogen.

Most remarkable of all is the power possessed by certain leguminous crops of obtaining nitrogen in situations where a grain crop might starve. It is a well known fact, that in order to secure good crops of clover, or of other leguminous plants, far less nitrogenous manure need be applied to the land than is required to grow a wheat-crop; and this fact is not a little surprising, because clover and the other leguminous plants contain particularly large quantities of nitrogen, and there is actually carried off in them from the land a great deal more nitrogen than is carried off in a wheat-crop. It is now known that leguminous plants are supplied, in some part at least, with nitrogen from the air, thanks to the activity of certain micro-organisms which live upon their roots, as has been explained in the chapter on Symbiosis. It is to be

remembered withal, that the term of growth of most crops which are grown in alternation with grain is longer than that of the grain-crops, and that the processes which lead to the production of nitrogenous food are probably most active at the times when these crops are growing freely, and have the greatest need of food.

Grain-Crops are apt to be injured by Applications of Rank Manure.

Some kinds of plants, such as wheat and barley (and flax), must not be fed too richly, lest they "run to leaf" and produce no adequate yield of grain, and become unable to resist the assaults of hurtful fungi. It is a matter of common notoriety, in England, that wheat which has been heavily and directly manured is particularly apt to be attacked by the micro-organisms which cause "blight" and "mildew." Years ago, when wheat was commonly grown in Europe on a clean, bare fallow, to which a certain amount of manure had been applied several months before seeding, it seemed to the men who practised this system of husbandry that a limit had been set to the amount of wheat that could be grown on an acre of land. They found themselves unable to force the wheat to yield more than a certain tolerably definite quantity of grain, for the moment they applied to the land any more than the usual quantity of dung, their wheat was apt to fail, because the plants ran to leaf and lodged before coming to maturity.

The same difficulty was encountered long ago in certain localities at the east of England on trying to grow wheat on deep, mellow loams rich in humus after these soils had been marled. Wheat grown on such land, either "after clover or after a summer fallow, became too rank to stand, and ran too much to straw to yield a large produce of grain." But on growing oats before the wheat, "the oat-crop being thrown in as a damper of the raging fertility of the soil," comparatively good crops of wheat were obtained. It was observed indeed, in England, at a very early period, that wheat does not thrive well either on very poor or very rich land. If the land was spent, or out of heart, the grain was poor, the ears short, and the straw light and small, while, if the land was too full of manure, the crop was apt to run to straw. To cite Cobbett's words, "It is well known that wheat-plants standing in ground too full of manure will yield very thick and long straws, but grains of little or no substance." But this running to leaf, which may be fatal for a wheat-crop, is, within due limits, often

enough not wholly undesirable in respect to broad-leaved plants, such as Indian corn, squashes, beets, potatoes, horse-beans, hops, and clover, and for rape also, provided of course that the exuberant growth is not too pronounced.

Preparatory Crops.

One of the most important improvements in the practice of rotation has depended on the discovery that it is only when manure is applied directly to the wheat-crop that it causes the troubles above mentioned. In point of fact, it was found out long ago that much better crops of wheat than had been obtained previously could be grown by applying an abundance of manure to certain preparatory crops, such as horse-beans and clover, which do not suffer from very heavy dressings of dung, and which leave the land in excellent condition, both physically and chemically speaking, for the growth of wheat. It has been said of beets, also, that they are an especially valuable crop, because they can bear both forcing and storing. (Frere.) One result of the introduction of phosphatic fertilizers in England has been the establishing of a practice of growing turnips with commercial fertilizers, and of saving dung for those clover-fields which are to be followed by wheat.

In addition to these peculiarities in respect to the influence of fresh manure, practical experience teaches that plants differ widely as to their ability to thrive on land where crops have been growing. Some plants grow well and others ill on land from which plants of the same kind have just been taken; and a similar remark would be true of land on which plants of another kind have been growing. Several of our commonest crops fail to succeed when sown after some kinds of plants, while they are known to grow well after certain other crops. Near Boston, June-grass will grow after June-grass apparently until the end of time, while red clover soon ceases to thrive after red clover. It is a world-wide maxim that barley grows well after wheat, although wheat seldom does well when sown after barley or after rye. In some parts of Germany, where rye is an important crop, it is said not to succeed at all after sainfoin. The influence of a preparatory crop to free land from weeds is often an important consideration. Thus, "potatoes kept very clean under the plough are an excellent preparation for flax; and turnips well hoed, the same." (A. Young.)

Exhaustive Crops.

Some of these differences in the power of plants to procure food from a given store manifestly depend upon facts of symbiosis, or blended growth, as has already been explained; while in other instances it would appear that certain crops may remove some one kind of food so completely that the soil is made unfit for the growth of this crop, or of other crops which have similar needs. I have myself noticed — in corroboration of the observations of Lawes and Gilbert — that it is practically impossible to grow Swedish turnips for several years in succession on a mediocre soil without fertilization. This fact is familiar to American gardeners, who have long known very well that many kinds of vegetables are apt not to grow freely after the rutabaga. But it has been shown by the experiments of Hellriegel that turnips have no means of getting nitrogen from the air. It has been said of the cabbage also, and of spinach, that these plants are apt to be so detrimental to crops which succeed them that it seems almost as if they had poisoned the land; the fact being that both these plants are "gross feeders" which "consume everything within reach," and especially certain nitrogenous constituents of the soil. It is plain, at all events, that in studying rotations the peculiar characters and habits of growth of the several crops need to be kept in view as carefully as the chemical constituents of the soil, or of the manure which is put upon it; for the power of each particular crop to assimilate materials from the soil is really the prime consideration.

As is manifestly the case with the wheat-plants just mentioned in their relations with dung, it may be said in general that the success of a given crop may depend largely upon the quality of the chemical constituents of a soil, rather than upon their kind or their quantity. It is conceivable, for example, that the crop may feed better upon one combination of nitrogen, or of phosphoric acid, or of potash, than upon another. Possibly it might do better with ammonium salts than with nitrates; better with diphosphate of lime than with triphosphate, or with the double silicates that contain potash than the double humates. But by long-continued cultivation of this supposed crop there may be established, by mere exclusion as it were, a vicious set of combinations in the land. It was thought at one time that "clover-sickness" might perhaps be explained in this way.

The Tillage of one Crop may be Bad for another.

Yet again, a field may be made unfit for some kinds of crops, and be well prepared for the support of others, by mere changes in the physical condition of the soil, brought about, as a result of the presence of the preceding crop, either by the methods of tillage practised for the sake of this crop, or by the roots and stubble which the crop has left upon the land. In rainy countries, it may often happen on clayey land, from which root-crops or late potatoes have just been taken, that no fit opportunity will present itself for tilling the land in preparation for winter wheat; and that the farmer — anxious lest he may fare worse by waiting longer — is led to plough the land at a time when it is moist and apt to puddle, so that it is left cloddy and by no means in the best possible condition for the growth of wheat. It is perhaps chiefly because of this risk of autumnal puddling that in many regions neither roots nor potatoes have been much esteemed as forerunners of winter wheat.

It need hardly be said, moreover, that different soils differ widely as to the amount of assimilable plant-food contained in them, according as manure has or has not been recently applied; or that, from the different styles of roots of different plants, different methods of feeding must result.

Structure of Plant-roots.

It is a popular impression that some plants, like lucern, and several other kinds of clover, throw out such large and long and numerous roots that they are able to extract nourishment from a large bulk of soil. We may contrast, for example, the very different habit of growth of root-crops, such as turnips, beets, carrots, and parsnips, and that of the grain crops; or we may look at some wild plants, like the beach-pea, that has enormously long roots, with which it searches for food far and wide among the stones at the heads of beaches; or like the horse-tail or scouring-rush of wet sandy places, which has, as the farmers say, no end of roots. Couch-grass and the Canada thistle are other familiar examples of plants whose pernicious creeping root-stalks fill the soil all about them; and so it is probably with many of the weeds that grow in what botanists call waste places.

On the island of Jersey, where by means of trench-ploughs the soil is tilled to unusual depths, the farmers do not hesitate to bury manure 12 to 16 inches deep for parsnips, for "this root pene-

trates extremely low and arrives at the manure." But for potatoes they prefer not to sink the manure so deeply, and to have the sets placed almost upon the manure. It has been observed there that potatoes do not derive much benefit from manure lying so extremely deep as this unless they are planted very deep. Yet it is noticed by American farmers that while it is well that some manure should be disseminated throughout the soil on which potatoes are to be grown, it is often advantageous to put in most of the manure rather deep for this crop. As a rule, manure may be ploughed under deeper for potatoes than would be necessary for Indian corn. "Potatoes naturally like coolness and moisture, hence a deep soil and food rather deep is best for them if the land is well drained." (Terry.)

Roots are Symmetrical.

From the very fact that they are commonly out of sight in the ground, our knowledge of the structure and habit of growth of the roots of plants is still imperfect. It has been clearly made out, however, that, when the condition of the soil permits their perfect development, roots grow according to definite architectural plans, which are just as symmetrical and characteristic for each particular kind of plant as the forms which are assumed by the plants above ground in respect to the arrangements of their stems, branches, twigs, and leaves. (Hellriegel.)

It has been found, for instance, on comparing the network of roots of barley, buckwheat, and clover plants of similar age, and grown under conditions favorable for perfection, that the three objects are as different, as well characterized, and as easily distinguishable one from another, as the plants themselves. Plants as nearly related as peas, lupines, and horse-beans have systems of roots which are very unlike, and the same remark is doubtless true of most other plants. All this on the supposition that the roots are growing in a light soil, of homogeneous character both as to tilth and fertility.

The very first roots that form are thrown out without any reference to the amount of plant-food in the soil. They will grow as well, or better, in moistened sand as in loam. Indeed, it is noticed by gardeners that more roots seem to be formed at the start in sterile soils than in soils which are fertile. It is only after the roots have attained a certain development that they are apt to linger in the vicinity of any special store of food which they hap-

pen to meet in the soil, and to grow there more freely than in the comparatively barren earth around it.

It must not be forgotten, however, that the power of roots to adapt themselves to circumstances is very considerable, or that they do habitually, and as a rule, develop most freely in those directions where there is least resistance to their progress, i. e. where the soil is open and mellow, and in spots where there are abundant supplies of food and a sufficiency of moisture. Thus it happens that the roots of any given plant may sometimes be found to have grown near the surface of the soil, and at other times at lower depths. Indeed, it may be said of actual field practice, that, in most instances, the manner of the development of the roots of a crop depends more upon the condition of the soil than on any inherent peculiarity of the crop.

Tap-Roots and Branching Roots.

One prime difference in the structure of roots depends upon the fact that, while many kinds of plants send down vertically a strong tap-root, with which the body of rootlets is more or less intimately connected, other kinds have no such central axis, but send out at once several or many branching roots, any one of which is as good as either of the others. Upon these main stems, as it were, the subordinate roots are arranged in regular rectilinear rows, which manifestly stand in some kind of relation with the twigs and leaves above ground. Indeed, the length and magnitude of the roots of any plant must depend ultimately, in any given case, on the vigor and general prosperity of the plant. Other things being equal, large, well-developed plants will have more abundant roots than smaller or less satisfactory specimens.

The number of rows or series of subordinate roots, and their positions upon the main roots, are different in each kind of plant, and form a characteristic feature or peculiarity of the plant. Some plants throw out lateral roots with great regularity, and at small distances from one another; while in other kinds of plants there are wide interspaces, and the arrangement is irregular.

In some plants the subordinate roots grow with equal degrees of rapidity, so that the oldest are always the longest, and the soonest beset with rootlets; while with other plants the growth of particular roots is much more rapid than that of others. Sometimes these free-growing roots are always the uppermost or oldest, while in other plants it is the lower and younger roots which exhibit this peculiarity.

According to Hellriegel, it is a mistake to classify plants, as has sometimes been done, as those which are deep-rooted or shallow-rooted, according as they have tap-roots or not. Grain-plants, for example, have no tap-roots. They send out at once, when vigorous, as many as 20 or 30 branching roots, which drive downward, often to great depths, when the conditions are favorable. From these main roots other roots of varying degrees of magnitude are thrown out, which are hardly any shorter than the main roots, though finer.

Depth to which Roots of Grain penetrate.

Many farmers have put upon record their astonishment on noticing the great depths to which grain-roots penetrate. Gasparin reports that in places where the banks of the rivers Rhone and Ardèche had caved in, he has seen the roots of wheat — as well as those of lucern and the mulberry — extending downward to a depth of almost ten feet, in order to reach ground-water that was percolating through gravel toward the river. Lucern roots he has often seen 13 feet long, and he tells of one preserved in the museum of Berne that is more than 50 feet long. W. I. Chamberlain having occasion, in Ohio, to lay some three miles of tile drain three feet deep in a field of hard, stiff clay, upon which wheat had been grown that year and the year before, noticed that every spadeful of earth thrown out of the trenches, even that from the bottom course, was full of fine wheat-roots, both live roots from that year's crop and half-decayed roots from the plants of the previous year. He did not try to determine how much deeper than 3½ feet the roots went. At the time of these observations the surface of the land was very dry. There had been no rain for a month; but at a depth of three feet the soil was fairly moist, and even at two feet there was a good supply of capillary dampness. It is plain from all this that there is no cause for surprise that wheat should habitually stand drought well, especially on clayey loam.

In a climate where rain is evenly distributed, there will naturally be less need of the grain-roots penetrating to so great a depth. According to Gasparin, there are excellent wheat-fields near Paris, the soil of which is not more than one foot deep, though in the dryer climate of Southern France a much deeper soil than that would be needed for the successful growth of wheat.

So, too, as regards the presence or absence of available plant-

food. According to Hilgard, the heavy, black, clayey, "adobe" land at the junction of the Sacramento and San Joaquin Valleys, in California, which "is rich in all soil-ingredients to an unusual degree," is so close of texture and so fertile withal that the roots of wheat rarely penetrate it to a depth of more than 2 feet, while in the sandy soils upon which wheat is commonly grown in California, the larger roots penetrate to a depth of 6 feet or more.

Schubart's Experiments.

In 1851, Schubart, a German farmer, made measurements of various roots which he washed out from the soil of fields where the crops were growing. In one somewhat exceptional instance he found on the tenth of November that the roots of wheat sown late in September extended to the depth of 7 feet Rhenish in a subsoil composed of sandy loam, while in a somewhat stiffer subsoil they went no deeper than 6 feet. In other trials, wheat sown at the end of September had roots 3 ft. 2 in. long at the end of April, and that sown at the end of October had roots 2 ft. 11 in. long. Six weeks later, i. e. at the end of June, the roots of the early sown wheat were 3 ft. 11 in., and those of the late sown, 3 ft. 7½ in. The soils in these cases were stiff loams.

The roots of rye sown at the end of August, in deep loam, had penetrated to a depth of 3 feet; some of them, indeed, to a depth of almost 4 feet in November of the same year, although the leaves of the plants had only reached a height of about one foot. At the same time rye that had been sown four weeks later had roots reaching to depths of from 1.75 to 2.25 feet, and leaves 4 to 6 inches high. Rye sown at the middle of September, on heavy land, had roots 3 ft. 9 in. long at the end of the following April, and they were only half an inch longer at the middle of June.

Tests of Roots of Indian-corn.

Professor King, in Wisconsin, has made elaborate experiments on the distribution of the roots of Indian corn. Nine days after the seed was sown he found that some roots had extended laterally to a distance of 16 inches, and that some of them had reached a depth of 8 inches. No roots were nearer the surface than 3 inches, at a distance of 6 inches from the seed. Eighteen days after the sowing of the seed, the tips of the longest lateral roots were 18 inches from the seed, and were 5 inches or more below the surface of the soil. The greatest depth attained at this stage was hardly 12 inches. Twenty-seven days after planting, the

longest lateral roots were 24 inches long, and their tips were 4 inches below the surface. The greatest depth reached was 18 inches.

In other trials, made in a somewhat different way, it was found on July 9, forty-two days after the seed was sown, and when the plants were about 18 inches high, that their roots had penetrated to a depth of about 18 inches, and had spread laterally to such an extent that the roots of the plants in one row had met and passed those of the next row, at a distance of 3.5 feet from the stalk. The surface roots sloped gently downward towards the middle of the space between the rows, where those nearest the surface were some 8 inches deep; but when the corn-plants had reached a height of nearly 3 feet, at the time of the last cultivation, and the entire soil down to a depth of 2 feet was filled with them, the surface leaders were only 6 inches deep. In a third sample, taken when the plants were coming into full tassel, the roots fully occupied the upper 3 feet of soil, and some of the surface leaders were scarcely 5 inches deep, though most of them were 6 inches deep or more at the middle of the spaces between the rows. At maturity, the roots reached to a depth of more than 4 feet, and some of the lateral leaders were within 4 inches of the surface of the soil at the middle of the space between the rows.

There are some old observations of Bonnet as to the length which the roots of lucern may reach, under favorable conditions, which far exceed the limits of ordinary experience, though, as was just now said, Gasparin has seen these roots more than 13 feet long. Lawes tells of them as penetrating 9 feet from the surface; and Marshall has recorded the fact that "the roots of sainfoin have been traced in stone-quarries to 10, some will say 20 feet deep." Thaer is said to have traced sainfoin roots 16 feet. To the deep-rooting habit of such plants as these is attributed their power of withstanding droughts.

Rapid Development of Young Roots.

The rapidity with which the roots of the young plants were developed in the instances above cited illustrates a very general fact which is true of most agricultural plants, viz. that in early youth, after a few leaves have been put forth, plants devote themselves specially to the development of a powerful system of roots before any extensive growth of leaves or stem occurs above ground. The shooting up of grain, for example, does not take place until after many roots have been developed.

The fact now in question has been proved, not only by measuring the roots, but even more emphatically by weighing them. That is to say, on contrasting the weight of the roots day after day with the weight of the stems and leaves, it has been found that, while the proportion of roots is very large when the plant is young, it diminishes constantly as the plant grows older. In the case of annual plants, the formation of roots seems to be finished by the time when ripening begins.

Schubart found that garden peas sown early in April, in stiff loam, had roots 10 to 13½ inches long at the end of a month, and 20 to 22 inches at the end of two months. When the plants were in blossom, their roots were 4 feet long.

Clover, examined at the beginning of April, the year after it had been sown, in not very heavy loam, had roots 3 ft. 6 in. long; while that sown two years before had roots 3 ft. 10 in. long.

The roots of orchard grass and timothy have been traced to depths of 4½ feet, and those of other grasses, notably English ray grass, to a depth of 4 feet Rhenish. King, in Wisconsin, found that while the roots of timothy, winter wheat, oats, barley, red clover and the meadow vetchling extended in the field nearly or quite to a depth of 4 English feet, the roots of June-grass were much shorter and barely reached to the depth of 26 inches.

In the experiments of Heinrich, oats, barley and peas were grown in special boxes, 13 feet deep, which had been filled with sifted garden earth, and the earth was finally washed away from the roots of the ripe plants. His results are given in the table: —

Plant.	Length of Roots. Feet.	Weight of Air-dried Roots. Grams.	Weight of Air-dried Straw and Chaff. Grams.
Oats	7½	43.75	61.5
Barley	6¼	27.50	76.5
Peas	1¾	6.00	31.5

Heinrich argues from these results, and from the behavior of the two crops in field culture, that the roots of oats are probably better able than those of barley to overcome obstacles in the soil. Tull, in his day, while insisting that certain crops require more food than others, was well aware that "some kinds of plants are of stronger make, and better able to penetrate the earth and forage for themselves. Therefore," as he says, "oats may succeed a crop of wheat on strong land, with once ploughing, when barley will not, because barley is not so well able to penetrate as oats, or beans, or peas are."

Volume of Grain-roots.

Hellriegel, in his turn, in order to get an idea as to the volume of roots of grain-plants, grew barley and oats in large jars of fertile earth, whence he washed out and measured the roots. Expressing his results in terms of total length, he found that the roots of a single well-grown mature barley-plant, laid out as a single straight line, were more than 140 feet long. In another trial, where the soil was less fertile and the growth of the plants less satisfactory, the length of root was 80 feet to the plant. In general, as would naturally be expected, the smaller the plant, so much the shorter will be its roots.

In the case of oat-plants, he found that the roots were 164 feet long at that period of growth when the stem was beginning to shoot, 125 feet when the plant was in blossom, and 150 feet when it was ripe. The fact that fewer roots were found as the plant grew older is attributable in part, perhaps, to imperfections in the method of measurement, and in part to the premature dying of some of the roots in the jars of earth in which the plants were grown.

The most surprising fact brought out by the research, however, was the completeness with which the roots of these grain-plants pervaded all parts of the earth which was at their disposal in the jars. In garden earth, for example, 200,000 millimetres of barley-roots occupied 3,800,000 cubic mm. of soil, i. e. there was 1 mm. of root to every 19 cubic mm. of earth. In other words, each millimetre of root had at its disposal a cylinder of earth 1 mm. high and 5 mm. in diameter, or it might be said that on either side of the root there was no more than 2½ mm. of earth.

In the case of oats, each mm. of root had rather less than 21 cubic mm. of earth at its disposal. In fertilized sand the utilization of space by the roots was even more remarkable, each mm. of the roots of middle-aged and mature barley-plants having here no more than 7.7 mm. sand at its disposal.

Roots of Peas, Beans, and Lupines.

Hellriegel studied the forms of pea, lupine, and horse-bean roots by growing the plants in moistened sawdust that had been slightly compressed, and obtained results of no little interest.

The pea has a strong tap-root, which, from the beginning, is covered thickly and tolerably regularly with lateral roots. Most of the subordinate roots start from the crown or oldest part of the

tap-root, and a comparatively small number of them grow rapidly, and attain considerable length. The formation of side roots springing from the tap-root continues with tolerable regularity as the plant grows older, though these side roots are now not so close together as they were at the crown. The throwing out of some exceptionally vigorous lateral roots is a characteristic peculiarity of the pea, and some of these roots grow to be as long and as large as the tap-root itself, and they have as many rootlets also. The general effect of the pea-roots is that presented by a stem very thickly beset with branches. The appearance of the roots indicates that any damage or disturbance experienced at one part of the net or mat would quickly be made good or compensated for by the action of some other part; and this supposition was found to be correct, on placing obstructions in the way of the roots.

The bean, like the pea, sends down a strong tap-root, from the crown of which numberless side roots are thrown off with great regularity. These side roots are stronger and stiffer than those of the pea, and their growth is more uniform and less energetic than is the case with pea-roots. As the tap-root extends downward, the side roots are thrown out at wider and wider intervals, so that the thickness of the root-mat diminishes from above downward.

Each of the side roots of the bean grows about as fast as the others, and the absence of exceptionally long and powerful roots distinguishes the bean very clearly from the pea. The general appearance of the bean-roots is that of a symmetrical cone inverted, with a dominant tap-root at the centre. So well provided is the bean-plant with roots, that it is not likely to suffer much harm when partial obstructions are encountered in the soil, or when some of the rootlets are injured; but the tap-root of the horse-bean is so much more prominent and important than that of the pea, that any injury to this organ, or impediment in the way of it, would do harm. A somewhat similar remark is true of beets also. Practical men have noticed that when young beets are transplanted great care must be taken not to injure their tap-roots. By paying due attention to this matter, young beets may be transplanted with success; but in case the tap-roots are broken by drawing the plants, the beets will grow "rooty and fangy," and be of little value.

Lupine-roots.

The yellow lupine has very different roots from either peas or

beans. There is first of all a thick, powerful, hairy tap-root, which goes down to a considerable depth before any lateral roots are thrown out. About the time when the third leaf appears, side roots begin to be sent out from the lower half of the tap-root, often from the lowest quarter of it; but these side roots are extremely sparse and irregular. As the plant grows larger, the tap-root still remains dominant, though side roots grow rather more freely than before. They never get to be so thick as those which spring from the crown of the tap-root of peas and beans.

Unlike peas and beans, the most energetic growth of the lupine-root is not at the top or oldest part of the root, but below, far away from the crown, and this peculiarity becomes more and more evident as the plant grows older. As compared with the highly symmetrical bean-roots, those of the lupine appear irregular and confused. It seems probable that the loss of rootlets would be felt much more keenly by lupines than by peas or beans, and that the plant is consequently less well fitted to cope with mechanical obstructions than either of them. (Hellriegel.)

Experiments made by Eckenbrecher illustrate the fact that lupines are better able than oats to take food from the subsoil. Bottomless boxes or frames were sunk in the ground, and filled with sterile sand, so that some plants could be grown in a layer of sand 1.5 feet deep, and others in sand 3 feet deep. No nitrogenous manure was added to the sand, but only the ash-ingredients necessary for plant growth. Into the subsoil, however, nitrate of soda was stirred, in both cases, at the rate of 67 grams to the square yard of surface. There were harvested grams of air-dried plants,—

	From ½ Yard Depth of Sand.	From 1 Yard Depth of Sand.
Oats (*a*)	677	220
Oats (*b*)	405	160
White lupines	1,398	837
Yellow lupines	1,147	687

Whence it appears that lupines are better able to utilize deeply buried nitrates than oats, although both crops would have been well suited if the fertilizer had been somewhat nearer the surface.

Clover-roots.

The roots of red clover are said to resemble those of the pea in outward appearance. The clover-plant develops a full set of roots during the first year of its life, as if it were an annual plant, and in subsequent years there is an analogous development of roots

every spring after the plant has first thrown out the shoots which come from the store of nourishment that has been kept over winter in the tap-root.

When the crop is mown, the case is somewhat different. By growing clover in glass jars it can be seen that every time the plants are mown they enter upon a new course of life. Before a single leaf or shoot appears above ground, there is an energetic exhibition of new life below the surface of the earth, where a multitude of rootlets are thrown out in every direction; whence it seems plain that the soil at the disposition of a clover-plant must finally come to be pretty fully occupied with rootlets. This habit of growth of the clover-roots, taken in connection with the nitrogen-bringing fungus which develops upon them, justifies the opinion of practical men that the soil is greatly improved for the succeeding crop when clover is allowed to stand for a second mowing instead of being ploughed under immediately after the first hay-harvest.

From the very fact that the clovers are perennial plants, it would appear that they must take up food in a somewhat different way from the ordinary annual plants, such as wheat or oats. The roots of annuals die as soon as the seed has ripened. They have but a single season in which to accomplish the work of a life. But the roots of perennial plants live on year after year, and they send out new roots and rootlets with considerable freedom on occasion. Hence it happens that, although the roots of perennial plants do not necessarily or even habitually go deeper than those of annuals, they occupy space in a different way, and probably occupy it more fully. It is not likely that the soil invaded by each new set of roots which are thrown out by clover, for example, is precisely the same soil as that occupied by the previous sets of roots, so that it may be said fairly enough that food is continually extracted from new stores.

Perennial Plants feed Advantageously.

In other words, it may be said that the complex of roots of a perennial plant has had opportunity during the life of the plant to collect food from a much larger volume of earth than could possibly have been drawn upon by the roots of a single annual crop. Moreover, it is not unreasonable to suppose that plants already equipped with a well-developed system of roots may have a certain advantage over young annuals in times of drought. If the surface soil should become dry, the roots of perennials would naturally

draw food as well as water from below, while in case the subsoil were over wet, the roots would find food at a higher level. If there happens to be but little plant-food in the soil, the crops whose roots most completely fill the soil will have the best opportunity to extract what food there is. All this, beside the habit common to most perennial plants of storing up in their bulbs or tap-roots a supply of food for next year's use; and in addition to the power of the roots of leguminous plants to take in nitrogenous food in a peculiar way by means of the nodules which grow upon them. On seeking to discover how many clover-roots were formed at different depths in the soil, Thiel found, —

Number of roots	100	53	33	25	20	11	6	2
At depth in inches	10	14	18	22	26	30	34	37

In a clover-field examined by John, six times as many fine roots were found in the uppermost 7 inches of soil as were found in the soil below this depth.

In speaking thus of the complex of roots of a perennial plant, it is important not to detract from or confuse in the least the fundamental conception that the food of plants is taken in, for the most part, by young and delicate rootlets, and by the little hairs which cover the rootlets. All is, the more roots there are, the more rootlets will there be or have been; or rather, the more roots there are, the better and the more complete will the distribution of the rootlets be.

Importance of the thorough Distribution of Roots.

The very great significance of an abundant supply of roots becomes even more plain on regarding the matter from a slightly different point of view. Bearing in mind the facts that the plant itself is immovable, that it needs certain kinds and amounts of food which must be taken from the earth, and that this food is taken in through certain active cells which are situated for the most part near the ends of the rootlets, it is evident that rootlets should be sent out and scattered in every direction, in order that their work may be accomplished to the best advantage, unless indeed the soil happens to be extremely rich.

There follows naturally from this conception one important lesson as to the theory of manuring. For inasmuch as it is plain that the absorbent rootlets can never occupy every part of the soil in which their plant is standing, it is certain that the plants of one

single particular crop can never by any possibility take up all the food which the soil contains. Hence, in applying manure to a poor soil, it will not do to argue that the land will be properly treated if there be put upon it precisely as much and as many fertilizing materials as the crop will take off. It is not in any man's power to put a limited amount of fertilizing materials in precisely the same places as those from which a crop has taken or will take its food. Consequently, in order to manure poor land well, it must be manured tolerably heavily. Generally speaking, it would doubtless be the part of wisdom to try to keep all plough-land in such condition that it should contain in the aggregate an amount of available plant-food equal to a considerable multiple of what any single crop could take off; because, no matter how carefully the land may be tilled, no one crop can ever gain access to every part of the land. But since no crop can ever reach the whole of the food, care should be taken to have such an excess of food in the soil that the crop can find within reach as much food as it wants. This argument may be seen pushed to its uttermost limits in the practice of market gardeners, who are accustomed to employ stable-manure in such enormous excess that their crops cannot possibly consume any large fraction of the plant-food which is contained in the manure.

Fertilizers not all Recovered in Crops.

So, too, in the experiments of Lawes and Gilbert, on the continuous manuring of grass-fields, only comparatively small proportions of the several fertilizers applied were recovered in the crops. Thus, of the potash estimated to be applied in the manure, during 8 years, 44 % were found in the total produce of those years, 22.5 % in that of the next 6 years, and 10.5 % in that of the succeeding 6 years, or in all, 77 %. But on deducting the amounts of potash contained in the hay obtained from unmanured land, it appeared that the potash recovered in the increase of crop was 30.5 % during the first 8 years, hardly 13 % during the next 6 years, and only 4.5 % during the final term of 6 years: in all about 48 % of that supplied.

As regards phosphoric acid, about 57 % of that applied to the land was contained in the total produce of 20 years, while the increased yield contained 33 %. Of the magnesia applied to the land, nearly 70 % was contained in the total produce of 20 years, but the increased yield contained only about 21 % of it. Of the amount of lime supplied in the manure during 8 years, only about

12.5 % was recovered in the total produce of that period, about 9 % during the next 6 years, and little more than 4 % in the last 6 years, making in all about 25.5 % in the 20 years; but the increase of the crops during these periods contained, during the first 8 years, only 3.5 % of the lime applied in those years, little more than 2 % in the next 6 years, and a small fraction of 1 % in the final 6 years; i. e. not quite 6 % in the 20 years. Of the nitrogen applied to the land, only a comparatively small proportion was recovered in the increase of the crops, as has been explained in another place.

Manures maintain Fertility.

In speaking of soils which contain clay, Gasparin has said that when such soils are saturated with manure they have a high agricultural value, and are capable of yielding large crops; but when they are not saturated, the crops they bear are always smaller than the equivalent of the manure with which they have been dressed. It may be remarked in passing, that the manifest importance of fully charging the root-space of a crop with plant-food goes far to explain and to justify an agricultural custom, common enough in many localities, known as "manuring in the hill," where instead of spreading manure broadcast upon the land, masses of it are thrown into the base of the hill, or into the furrow in which the seeds or sets of the crop are to be planted. There can be no doubt that this method of fertilization may have merit in many situations; it is constantly put in practice in horticulture.

But it may none the less be true, generally speaking, that in ordinary farm practice the purpose of manuring is to keep up the fertility of the fields, and to maintain in the soil a proper amount of fermentation, rather than to create fertility. It is the natural strength of the land that insures the necessary excess or multiple of plant-food; and by manuring compensation is made for what has been taken away, as well as provision for maintaining the excess. It is conceivable, of course, when the natural strength of land is great, that the fertility of such land can be kept up by adding to it no more than precisely what the crop has taken off, or even by adding less than the crop has taken off.

Christiani in Germany grew crops during 45 consecutive years on a rich alluvial upland soil, on some fields without any manure, on others with heavy dressings of farmyard-manure, and on others with light dressings. During the 1st and 2d terms of 8 years

(1827–34 and 1835–42) no noticeable economic advantage was got from the manure; i. e. the increase of crops on the manured land was worth no more money than the manure had cost. But during the 3d term of 8 years (1843–50) the natural fertility of the land began to show signs of failing, and the influence of the manure thus became plainly visible, though it was still true that no advantage was got from heavy dressings of dung, since the heavily manured fields gave crops that were hardly any larger than those got from the lighter dressings. It appeared clearly, however, that the fertility of the undunged land had been seriously impaired by such incessant cropping, and in subsequent years this truth became even more plainly evident. After the year 1850, the crops obtained from the unmanured fields were decidedly smaller than those got from the manured fields, and some of the unmanured crops (sugar beets) did not repay the cost of producing them. Until the year 1850, no other crops than potatoes, wheat, barley, oats, and rape had been grown, but sugar-beets were now introduced, and during the next term of 5 years (1851–55) this crop was grown three times, in alternation with oats and barley. Under the exhausting influence of the beets, the merit of the manure became well marked, and the heavily manured fields did rather better than the lightly manured.

After the experiment had been continued during 32 years, trials began to be made on a part of the hitherto unmanured land, to see how quickly it could be brought back to its original condition of fertility. In 1859, and in subsequent years, one-half of the unmanured field received dressings of farmyard-manure, with the result that after a year or two excellent crops were again obtained.

Accumulation of Nitrogen in well-manured Land.

In order to illustrate the natural and the increased strength of land as regards nitrogen, the following tables, drawn up by Lawes and Gilbert, may be cited. It shows the quantities of nitrogen in certain soils of their experimental wheat-field after the removal of 22 successive crops: —

Depth of Soil.	Wt. of soil to the Acre.	Lb. of Nitrogen to the Acre. Unmanured Land.	Land which got 14 tons Farmyard-manure.
1 to 9 inches . .	2,287,155	2,493	4,304
10 to 18 " . .	2,712,508	2,002	2,197
19 to 27 " . .	2,848,973	1,598	1,764
Total 27 " . .	7,848,636	6,093	8,265

More recent determinations, made after the manure had been applied some years longer, showed more than twice as much nitrogen in the first 9 inches of manured soil as was contained in that which was unmanured. Meanwhile, a very large quantity of nitrogen was lost altogether through nitrification and leaching, and perhaps by exhalation also, after the destruction of one or another of its compounds. The following table shows the disposition which was made of the nitrogen of the farmyard-manure that was applied to wheat during 22 years: —

	Per Acre.	Per Cent.
Pounds of nitrogen supplied in farmyard-manure during 22 years	4,415	
Recovered in increase of crops	470	10.7
Not recovered in increase	3,945	89.3
Residue in soil 27 inches deep	2,172	49.2
Not recovered in increase or in the soil	1,773	40.1

It appeared, in fact, that but a small proportion of the nitrogen supplied as farmyard-manure was recovered in the increase of the crops, and that the rate of recovery decreased with the lapse of years, though there remained in the soil a considerable slowly available residue. The large loss by nitrification and drainage would probably be less in any ordinary rotation of crops, since the non-grain-bearing plants would be better fitted than wheat to collect and hold nitrates.

Development of Roots at different Depths.

Hellriegel studied the development of the roots of plants in still another way, and obtained results which are specially interesting as illustrating the very great influence which the character of a soil may have on the manner of growth of the roots within it.

An earth-borer, made of strong sheet-iron, which was nearly nine inches in diameter in the clear and some ten inches high, was thrust into the soil of the field where the crop to be examined was growing; the soil outside the borer was then dug away, and the latter turned down to break off the core of earth within it. The root fibres at the bottom of the core of earth were then counted, the earth was shaken out from the borer, and the instrument again thrust into the soil at the very place from above which the previous core of earth had been taken. The process of boring was thus repeated until no more root-fibres could be found in the earth. The circle of earth cut out by the borer measured 62 square inches, and the numbers of root-fibres enumerated below all refer to this

area. The borings were made at times when the plants were in blossom, or just about to blossom, i. e. at a moment when the roots would naturally be fully developed. Some of the trials were on high-lying land, 13 to 100 feet above the ground-water, and others were on low-lying land, where the ground-water was not very far off.

I. *Winter Wheat* on high land. The soil consisted of two feet of loamy sand overlying coarse gravelly sand. The soil proper contained humus to the depth of a foot, but the second foot of soil had no humus. There were found at a depth of

8 inches	(in the loam)	820	root-fibres.	
21 "	(in loamy sand)	200	"	"
31 "	(in gravelly sand)	26	"	"
39 "	(in gravelly sand)	0	"	"

II. *Winter Wheat* on low land. The soil of field "A" was rich in humus at the surface, and consisted of a foot of sandy loam, below which there were one to two feet of clayey river-loam overlying clear sand. There were found at a depth of

8 inches	(in the soil proper)	558	root-fibres.	
15 "	(in river-loam)	218	"	"
26 "	(in sand)	83	"	"
33 "	(in sand)	106	"	"
41 "	(water-table)	0	"	"

In another low-lying wheat-field, "B," the soil consisted of peaty humus to a depth of 17 inches, with a subsoil of 7 inches poor in humus, beneath which was a layer 2 or 3 feet thick of coarse gravel overlying blue plastic clay. Here there were found at a depth of

8 inches	(in the loam)	432	root-fibres.	
17 "	(in clayey sand)	344	"	"
23 "	(in clayey sand)	149	"	"
31 "	(in gravel)	119	"	"
39 "	(in clay)	98	"	"
48 "	(water-table)	0	"	"

III. *Red Clover* in the second year of its growth, on high land. The soil consisted of 2 feet of loamy sand overlying coarse sand. The upper half of the soil proper contained humus, and the lower half none. There were found at a depth of

9 inches	(in the loam)	874	root-fibres.	
18 "	(in loamy sand)	340	"	"
26 "	(in loamy sand)	185	"	"
32 "	(in coarse sand)	28	"	"
41 "	(in coarse sand)	10	"	"

IV. *Red Clover* on low-lying land. The soil consisted of sandy loam three feet deep, of which the uppermost 18 inches contained humus. Below the sandy loam there were 8 to 3.5 feet of clayey river-loam, and below that clean sand. There were found at a depth of

9 inches	(in the loam)	729	root-fibres.
20 "	(in the sandy loam)	87	" "
24 "	(in the sandy loam)	56	" "
32 "	(in river loam)	34	" "
40 "	(in river loam)	32	" "
43 "	(in the sand)	74	" "
51 "	(water table)	0	" "

Similar trials were made in fields of oats, barley, rape, lucern, lupines, and winter rye, with analogous results. It appeared from these experiments and others that rape-plants had the largest number of subordinate roots (1,275 fibres were counted at a depth of 9 and 685 at a depth of 17 inches), and that flax and buckwheat came next. Then came the different kinds of clover, peas and beans. After them came the various kinds of grain, and finally lupines, which had the least number of roots of all the plants examined.

No marked differences were noticed as to the depths reached by the roots of different kinds of plants, and it seems plain that the agricultural plants do not differ from one another much in respect to this particular. On the high-lying land, the great mass of roots of all the crops was found in the soil proper, i. e. in the more fertile and porous layers near the surface; and even in the low-lying fields only a small proportion of the roots went down to the poorer subsoil, — not more than about 10 % of them.

It will be noticed that the low clover-field and one of the wheat-fields above cited are exceptions to the general rule, that the number of roots diminished regularly with the depth. In both these instances a considerable number of roots were developed in the lower moist sand after the plant had been at the trouble of pushing through the clayey loam of the subsoil. But, as a general rule, only scattering root-fibres were found in this poor land at depths greater than three feet. Undoubtedly, a very different state of things would have been met with if similar trials had been made in deep moist loams.

Ashes of certain Crops.

The following table, drawn up by S. W. Johnson, gives the

average contents, in per cents, of fertilizers in the ashes of several common crops.

		Alkalies.	Magnesia.	Lime.	Phosph. Acid.
CEREALS.	Grain (without husk) .	30	12	3	46
	Straw	13–27	3	7	5
LEGUMES.	Kernel	44	7	5	35
	Straw	27–41	7	25–39	8
ROOT CROPS.	Roots	60	3–9	6–12	8–18
	Tops	37	3–16	10–35	3–8
GRASSES.	In flower	33	4	8	8

Fertilizing Matters carried off by Crops.

The following table, likewise copied from Johnson, gives the weight in pounds of produce taken annually from an acre of good land by the several crops, as well as the weight of the more important constituents in these crops.

		Crop.	Nitrogen.	Ashes.	Phosph. Acid.	Potash.
WHEAT.	Grain	1,840	34	32	15	10
	Straw	4,600	14	207	8	39
	Sum	6,440	48	239	23	49
RYE.	Grain	1,470	28	25	12	9
	Straw	3,500	12	140	4	27
	Sum	4,970	40	165	16	36
BEANS.	Seeds	1,840	76	60	20	27
	Straw	2,700	33	138	14	34
	Sum	4,540	109	198	34	61
BEETS.	Roots	36,800	88	353	22	158
	Tops	9,200	26	173	11	69
	Sum	46,000	114	526	33	227
CLOVER		6,000	130	390	25	105
GRASS		4,000	53	246	13	58

The rye-crop takes only one-third as much nitrogen as a clover-crop or a beet-crop. Wheat takes twice as much phosphoric acid as grass, and two-thirds as much as beans and beets. About the same quantity of potash goes off the field in wheat as in grass, though it does not necessarily go off the farm, while beets and clover take up a good deal more potash than grass.

It is to be observed that tables such as these do not teach, as has sometimes been supposed, what manures to apply in any particular case to either of the crops in question; for the soil might contain already an abundance of most of the things needed, and

the plant still fail to thrive, because some one essential ingredient is absent.

It is true, moreover, as has been said, that different plants have very different powers as to getting at, extracting, and using the stores of food which may be contained naturally in any soil; and in general it appears that each particular kind of crop acts in its own peculiar way upon the land, and takes away from the soil, or from the manure which has been applied to it, more or less of each one of the substances which are necessary for the growth of plants. A remarkable instance of this effect is seen in the power of turnips to remove nitrogen from the soil. Practically, it is advantageous, on this account and under ordinary circumstances, to change from time to time the crops which are to be grown upon any given field. If one and the same crop were to be grown year after year upon the same piece of land, there would be a tendency to reduce unduly the proportion of the substances which are preferred by this crop, or which can be extracted from the soil by this crop. The tendency would be to accumulate in the soil those substances for which this crop has least need, but which might be highly useful for feeding some other crop. In ordinary language, there would be risk of exhausting the soil to such an extent that the crop in question could no longer be grown upon it. But by planting different kinds of crops from year to year, the preferences of one kind of plant may be made to counterbalance in some measure those of another, in such manner that the tendency to exhaustion may be greatly abated, or even annulled.

Meaning of the Word Exhaustion.

It is to be noticed that the word "exhaustion," as employed in agriculture, usually has no very precise meaning. In very many instances the idea rests on the money value of a crop and the cost of growing it, rather than on any accurate or scientific conception as to the condition of the soil. It is true enough that, in many situations, land may be utterly ruined by improper or careless cultivation, such as permits the surface soil to be washed away bodily by rains. But no such destruction as this can be reached by the taking away of nutritive matters, by any system of mere cropping, no matter how ill-considered it may be. Ordinarily, a soil is said to be exhausted when it has been merely run down or put out of condition by repeatedly cropping it year after

year without adequately manuring it. But this state of things may be corrected, as a general rule, — with some trouble, it is true, — by manuring the land heavily, and exercising good judgment for a year or two as to the kinds of crops to be grown.

According to M. Whitney, some kinds of soils may be impoverished by the injudicious application of fertilizers which alter the arrangements of the soil-particles and render the soil less retentive of moisture than it was naturally. Speaking of southern Maryland, he says: "The deterioration of lands is due to, or is accompanied by, a change in the arrangement of the soil-grains, changing the relation of the soil to the circulation of the water. This change in the appearance or texture of the land is quite apparent to the eye [and is perfectly familiar to the farmers], and one can judge of the condition of the land by the general appearance of the soil." To this category may perhaps be referred an instance reported by Gasparin. It has been repeatedly observed, he says, when certain highly calcareous soils in Vaucluse (France) are dressed continually with oil-cake, that they soon become exhausted. The humus natural to the soil gradually wastes away, and further applications of oil-cake cease to produce much useful effect. But if a dressing of farmyard-manure be interpolated after two manurings with the oil-cake, or if the land is manured constantly with a mixture of oil-cake and farm-manure, commingled in such proportion that the oil-cake shall supply two-thirds and the farm-manure one-third of the nitrogenous matter, the fertility of the land can readily be kept up.

In many cases land might be put out of condition temporarily by merely ploughing up an undue quantity of subsoil, though the crude earth thus brought to the surface might become fertile enough after two or three years' exposure to frost and air. Chaptal, writing in 1823, has said, "Agricultural people are familiar with this fact, and they say of it that the soil is not ripe, that it is not seasoned, that it is not aired, etc.; and they say that the air deposits fecundating germs on the soil." In Germany, it would have been said, even many years ago, of land thus out of condition, that it is not in a good state of fermentation.

The risk of "spoiling" soils that contain clay or silt by ploughing them when they are wet, has been insisted on under the head of tillage. The danger that land may be injured permanently in this way seems to be greatest in countries where the summers are

hot and dry, — though the land is moist enough in the spring, — and where the frosts of winter are not strong enough to loosen the indurated earth. Under these conditions, the hardness induced by the baking action of sunshine on the puddled earth may sometimes endure for several years, as was set forth ages ago by several of the Latin writers on husbandry.

It is true, indeed, of some exceptional plants (notably of turnips), that they would speedily cease to yield any appreciable return if the attempt were made to grow them continuously without manure on a soil of ordinary quality, although this very land might still be fairly fertile in respect to grain and grass, and many other crops. As bearing on this idea, it may be said that Gasparin, writing in Southern France of the injury which may be done to some soils in that locality by ploughing them when they are wet, or even when they have been no more than half wetted by a recent rain, notes the fact that on light land in particular, which has been "spoiled" in this way, such a multitude of weeds — charlock, wild poppies, chamomile, etc. — spring up that the fertility of the soil is perceptibly diminished by what they take from it. Of course these weeds help also to smother the young grain-plants in case any of them are struggling to make head upon the unfriendly soil. As was said on a previous page, it is known to be true that several kinds of vegetables will not grow well where turnips have sapped the land.

But, strictly speaking, a soil is exhausted, as regards any particular crop, whenever the cost of cultivation comes to as much as the crop is worth. The value of a crop depends upon the demand for it, and the cost of carrying it to meet the demand. In the vicinity of Boston, for example, rye was at one time a profitable crop, thanks to a brisk demand for long unbroken straw; but owing to the cost of transporting this bulky commodity, there may have been at that time little if any profit in growing rye as a field crop a few miles farther back in the country, and it might have been said with truth of fields 30 or 40 miles distant from the city, that the land was "exhausted," and unfit even to grow rye, although that very land may have been capable of yielding more rye and more straw to the acre, and at less cost, than the land upon which rye was profitably grown near the market.

Clover Sickness.

There are some rare instances, it is true, of crops which may

fail utterly when sown in too close succession on the same field, no matter how well the land is manured; and in these cases also it is often said that the land is exhausted, though it is evident enough that the word is here used in a sense somewhat different from that which is habitual. When land falls "clover-sick," for example, and will no longer bear clover, no matter how fertile the soil may be naturally, or how bountifully it has been manured, it is proper enough to say that the field is exhausted in respect to this crop and for the time being. Lawes and Gilbert urged, indeed, some years ago, that the failure of clover, when attempts are made to grow it too frequently on a given field, may perhaps be due to the want of a sufficient supply of certain organic compounds in the soil; but since the discovery of the fact that the growth of clover, and of other leguminous plants, is intimately connected with that of certain micro-organisms attached to the clover-roots, which take nitrogen from the air, a more probable inference would be that the clover-plant may finally be injured through the accumulation of hurtful chemical products which result from the activity of the micro-organisms. Lucern and madder — which was formerly grown for dyers' use in the South of France — are both crops apt to "exhaust" the soil, but madder will grow extremely well on "exhausted" lucern-fields when they are broken up (Gasparin), manifestly because of the nitrogen with which the lucern has charged the land.

Fairy Rings.

One striking illustration of the significance of rotation is afforded by the so-called fairy rings in old grass-fields. These fairy rings are circles of grass of coarser growth and greener color than the grass on the remainder of the field. They are caused by the growth of a fungus, which, starting from a spore which happens to have been sown at a particular point, grows, bears fruit, and dies, and by its decay affords nourishment to the grass. Subsequently a new crop of the fungus springs up around the original central point, from spores shed by the first plant, and afterwards still another crop grows just outside the first ring; and so the process goes on for a long term of years, the ring being constantly enlarged until some accident destroys it.

The English chemist, Wollaston, suggested long ago, in explanation of this peculiar growth, that the fungus exhausts the soil of some essential ingredient, — the organized matter, namely, upon

which it feeds, — so that the spores which fall upon that spot find it to all intents and purposes a desert. But, on the other hand, the grass finds a richly manured soil where the fungus has just decayed; and since the fungus contains much nitrogen, the grass takes on the deep green color due to nitrogenous manures. The analyses of Way have shown that the decaying fungus is rich also in phosphoric acid, potash, and the other ash-ingredients which are essential for the growth of grass. Lawes and Gilbert found furthermore that the soil within rings examined by them, which had been sapped both by the fungus and the grass, contained some 12 % less nitrogen and nearly 16 % less carbon than the outside soil which had not yet been attacked by the fungus. In some cases, it was estimated that the soil must have lost about 8,000 lb. of carbon per acre.

Principles of Rotation.

From considerations such as have been urged above, several agricultural writers have laid down the principles of rotation in the following terms: —

Every plant removes more or less of fertilizing matters when carried off from the land.

But all plants do not carry off the same kinds or amounts of fertilizers. Nor do different plants exhaust the soil in the same manner. There is a wide difference between peas, clover, and other leguminous plants which are fed with nitrogen from the air, and the cereal grains which take nitrate-nitrogen from the soil.

Even when fed out upon the farm, all plants do not restore to the soil the same quantity nor the same quality of manure.

Some plants suffer much more than others from the presence of weeds. They cannot grow freely on land which is partially occupied by some other kinds of plants. Such crops not only need to be tilled carefully, but they should follow a hoed crop. It was an old rule, for example, that nettles could be destroyed by sowing hemp-seed among them; and oats are thought to be specially apt to smother grass.

Finally, all crops are not equally favorable to the growth of weeds, the nourishment of fungi or insects, or to the tilth of the land.

Rotation is often Unnecessary.

It is possible, of course, in many cases, to do away with rota-

tion by manuring the land freely with the things best suited to the crop we wish to grow. In very rich land, of not too fine texture, there is often little or no need of rotation. Most gardens are so fertile that the rotation of crops in them would have no significance except as a means of avoiding some insect, or fungus, or weeds, or the impaction of the land. As Tull said, "It is seen that the samé sort of weeds which once come naturally in a soil, if suffered to grow, will always prosper in proportion to the tillage and manure bestowed upon it, without any change." Illustrations of this idea are seen every day in asparagus-beds, and in the old fields and pastures of Europe also. It is claimed, indeed, as one particular advantage of asparagus, that it is a plant which will produce crops for twenty years in succession without renewal. So, too, farmers are apt to grow carrots year after year upon one and the same field; and a similar remark is true of onions and celery, and of the Lima bean in the Middle States. It is true of rhubarb also, and of some other garden-plants. Hemp may be grown year after year without intermission. Some of the hop-grounds of England, on deep loams overlying chalk, which are still in full perfection, are said to have been planted more than 150 years ago. In other localities hops are said to stand well for 8 or 10 or 12 years on wet clayey soils that are not well drained, and from 12 to 20 years — sometimes 40 or more — on dry loamy soils overlying porous sandy rock. Fruit-trees, and especially grape-vines are often grown incessantly during very long terms of years.

On the Continent of Europe sugar-beets are sometimes grown continuously during several successive years — on land naturally fertile and well suited to roots — by means of dung and fertilizers; and the beets grow large and strong, unless they are interfered with by worms, insects, or drought. But, from the point of view of the sugar-maker, there is an objection to the growing of beets upon land that has been newly or heavily manured, because the roots are apt to be highly charged with saline matters, and to yield less sugar than is desired. The presence of an excess of saline matters in beet-juice hinders the crystallization of the sugar, and diminishes the value of the juice. For a similar reason, beets that have been grown after clover are not liked by sugar-makers, although they grow to a large size. They are said not to yield well, as to sugar, and to take up much saline matter from the decaying roots and stubble. It is on this account that

— contrary to old usage and tradition — beets are now sometimes grown in Germany immediately after wheat. The wheat receives the manure, and the beets thus escape from the influence of the rankness of fresh manure; but it is noticeable that a kind of wheat is grown which has a peculiarly stiff straw and is not so apt to lodge as some other varieties.

With regard to onions, although they sometimes suffer so severely from the attacks of hurtful fungi (and of insects) that they can no longer be grown with profit on the infected fields, it is none the less true that in the absence of these pests the crop often succeeds particularly well on old land that has long been cultivated, while it may grow very badly, or even fail altogether, on new land. Practical men seem to be inclined to attribute this apparent capriciousness as much to the texture of the soil as to its chemical character.

It is no uncommon thing in Europe to grow potatoes year after year, or with infrequent omissions, on the same fields, in localities where the tubers are used for distilling, or for making starch or glucose; and it has been found that this practice may there be persisted in — where the potatoes are to be used for manufacturing purposes — without any particular diminution of the yield, provided, of course, the fertility of the soil is kept up by manuring. Boussingault narrated long ago that in South America potatoes are habitually grown on the same land without interruption, and that the crops obtained are of excellent quality. All this in spite of the well-known fact that potatoes sometimes give heavier crops on newly broken grass-land than on land which has previously been tilled and manured. As has been said already, there is in this country an objection to growing potatoes continuously, in that the land may become charged with the scab fungus, which can live in farmyard-manure and in the soil also from one year to another, and may greatly injure the appearance and the sale of the crop. The persistence of the Jerusalem artichoke, when once grown upon land, is well known. Gasparin mentions an instance where it was cultivated continuously for 20 years and then purposely extirpated.

Grain may be Grown Continuously.

Boussingault mentions that maize has been grown incessantly in many parts of Peru since a period long anterior to the discovery of America; and that on the plateaus of the Andes there

are wheat-fields which have annually given good crops for more than two centuries. Arthur Young observed a farm in South-eastern Ireland, which was manured every year with sea-weeds and calcareous sea-sand, where the land was said to have borne 90 successive crops of grain, without the intervention either of fallows or grass-fields. Gasparin has described fields in the South of France which had yielded excellent crops of wheat during 40 successive years; and it has often been remarked of wheat that there would be no difficulty in growing it on good land year after year, effectively and profitably, if the land could but be kept free from weeds, insects, and fungi. To this end, the plan has occasionally been put in practice of paring and burning the wheat-stubble every year, together with any weeds or couch-grass that might subsequently be brought to the surface by the implements of tillage. Indeed, the experience of Tull showed long ago that, in so far as mere plant-food is concerned, wheat may perfectly well be grown year after year upon one and the same field; and, as is well known, Lawes and Gilbert have thus grown it during 40 successive years and more. According to Tull, the true cause why wheat should not be sown immediately after wheat, particularly on stiff soils, is that the surface of the ground becomes hard and impacted during the long period (nearly a year in England) that the first wheat occupies the land. Seedtime follows so soon after harvest that, generally speaking, there is not time enough to till the land so much as a second crop of wheat requires. Tull admitted, moreover, that one point specially to be guarded against was the risk that the wheat might become infected with the smut fungus. In his own words, "The strongest objection that has been yet made against constant annual crops of wheat is, that those grains of the precedent crop which happen to shed and grow in the following crop will be in danger of smuttiness, for want of changing those individual seeds. . . . But in five years that I have had these annual crops, this objected inconvenience never has happened to me. The reason I take to be that a crop very early planted is not so apt to be smutty; and if it be not planted early, the grains that are shed grow and are killed [by his horse-hoeing] before or at the time of planting the next crop." In some parts of this country, the prevalence of the Hessian fly has taught the farmers of those localities that it is not well to have wheat follow wheat.

In reporting their experiments on barley, Lawes and Gilbert note as—

"A very remarkable and very significant fact, that not only by farmyard-manure, but also by artificial manures containing no carbon, an average of not far short of 50 bushels of barley grain (of 53 or 54 lb. weight), and nearly 30 cwt. of straw, or much more than the average crop of the country under rotation, should have been obtained by the growth of the crop year after year on the same land for 20 years in succession. Not only was such an average obtained over the 20 years, but there was even rather more grain, higher quality, only little less straw, and nearly identical total produce over the second, compared with the first ten years, showing that there had been practically no exhaustion by the continuous growth during 20 years of such large crops under such conditions of soil and manuring. . . . The practice of growing barley for so many years in succession, by any means whatever, is not recommended for adoption in practical agriculture; but the extraordinary results which have been recorded are not the less instructive and important on that account."

A writer on the fen-lands of Cambridgeshire in England (Mr. Jonas) has said: "The great difficulty in describing the system of cropping is that no regular or uniform system is adopted. The soil has so much natural or virgin strength, that with some farmers it appears their whole study is how to tame it down; and this they endeavor by making wheat succeed wheat, then oats, again wheat, wheat again, then oats, then wheat; and by this time they have got the land so full of couch-grass as to be induced to give it a rest."

Rye also can be grown after rye, and there are said to be some sandy regions in Europe where rye is grown wellnigh continually upon the same fields. Indigo and sugar-cane are other crops which are seldom or never rotated. Indeed, there are many crops that might be grown for almost any number of years consecutively on the same land, provided that money and labor enough were expended in putting the soil into the proper chemical and physical conditions. But to do this would usually cost more than to rotate the crops. At all events, it has hitherto been found more profitable in the main to combine the rotation of field crops with the judicious use of manures. In the vicinity of large cities, where manure is abundant, there has never been felt so strong a need of rotation as in the districts which are distinctly rural. A similar remark will apply to countries made fertile by irrigation, and to a certain extent to those manured with sea-weeds.

Some Crops prefer New Land.

The fact must not be lost sight of, that, in direct opposition to what has just been said of carrots, onions, hemp, and asparagus, there are some plants which succeed particularly well on new land. Strawberries, for example, grow luxuriantly on new land; but after a few years they tend to degenerate, and are supposed to need a fresh soil. But it is said, in this case, that the trouble depends on the manner of growth of the strawberry-plant. Since new plants grow each year from the crowns of the old roots, it may happen, after this process has been repeated during 3 or 4 years, that many of the plants will no longer have any proper foothold in the earth. It is true, moreover, that strawberry-beds are apt to be injured by the attacks of some fungus, insect or worm, which destroys patches of the plants here and there. It is on this account, perhaps, that market-gardeners in New England have sometimes maintained that strawberries are apt not to do well after potatoes. (G. M. Nichols.) One advantage accredited to new land is its comparative freedom from the minute, thread-like nematode worms which often do very serious injury by attacking the roots of vegetables and of most garden-crops.

Another matter noticed by practical men is, that — while there are some plants which seem to have no need of humus, such as the Teltow turnip for example, or most emphatically the potato, which often does extremely well on mere gravel or sand if only it be supplied with dung and water — there are other plants that prosper best on soils rich in humus, notably celery, white mustard, cauliflower, and the rutabaga, as will be stated on a subsequent page. It is said that, although peaty soils are not specially well suited for beets (Voelcker), this crop may nevertheless be grown on peaty land with better chances of success than turnips. It is notorious, withal, that turnips cannot be grown continuously. Beside the risk of injury from insects and fungi, this crop is known to sap the land in a very peculiar way. Unlike wheat and barley, which may be grown on land naturally good for a long term of years, with only slow diminution of the yearly crop, turnips soon fail altogether unless the land is manured.

Turnips and Peas need Change.

It is true that, under the ordinary conditions of farming, good crops of turnips may be grown by means of phosphates without any direct application of nitrogenous manures; yet if the condi-

tion of the land is reduced by the removal of one or two crops of turnips, it will be found impossible to grow another remunerative crop of these roots without a direct application of nitrogen. On analyzing the soil of fields where root-crops had been grown during several successive years, a marked decrease in the amount of nitrogen proper to the soil was detected. Indeed, on those parcels of land to which no nitrogenous fertilizers were applied, the percentage of nitrogen, after the experiment had been continued 27 years, was found to be lower than in any other arable land on the farm. (Lawes and Gilbert.) The fact that turnips are grown in some localities as a preparatory crop for wheat depends on the circumstance that they are eaten off the land by sheep, which consolidate the soil and manure it. A similar remark will apply to a very old custom of growing rape for sheep-fodder. It is familiarly known, also, that rape does best on land where this crop has never before been grown, even when the soil is particularly well suited for rape. When grown at frequent intervals, during a series of years, on the same land, the yield gradually diminishes, even in cases where 6 or 8 years are allowed to elapse between each of the rape-crops, and when they are grown after bare fallows. (Walz.)

Peas commonly do best when sown not too frequently. An interval of 5 or 6 years is said to be appropriate, though one reason why they fail seems to be the accumulation of nematode worms upon their roots, as has been stated in the chapter on Symbiosis. It has been said, indeed, of light land in some parts of Germany, that peas should not be grown on it in a rotation oftener than once in 8 years, because they are apt to suffer severely from the attacks of the pea-beetle.

On the other hand, M. Whitney, in describing a soil in Maryland, not too light for wheat, which is considered to be good for tomatoes, corn, and cabbage, although these crops do not ripen so early upon it as on lighter land, says: "Peas do well on this land, but they cannot be grown two years in succession, for the large amount of nitrogenous matter in the roots and vines makes the soil very close and heavy, and the second year there is a large amount of pea-vines, but a very small crop of peas is obtained from them. Wheat is nearly always sown after the peas, then grass, followed by Indian corn, and then peas again. Some such rotation as this is necessary to keep the land open and in good

condition." Lawes and Gilbert have found, too, that land soon gets "tired" of horse-beans. At first these observers got good crops of beans, but it soon appeared that "under no condition of manuring could good agricultural crops of beans be obtained year after year."

Clovers are Capricious.

Most important of all, however, is the well-known case of red clover, which often fails utterly to grow on land whence a clover-crop has recently been removed. In numberless localities, the only known way of growing red clover with success is to allow a considerable number of years to elapse before trying to repeat this crop on land which has already borne it. There are some regions, it is true, where clover can be grown every fourth year; but it has long been a familiar experience of European farmers that red clover can seldom be counted upon when sown oftener than once in 8 or 12 years. On many German farms the arrangement of crops in rotations, and the lengths of the rotations, are made to depend largely on the number of years which, as experience has taught, must be allowed to elapse after one clover-crop has been taken before another good clover-crop can be grown.

What is true of red clover is likewise true in some measure of most leguminous plants. Thus it has been said of regions where red clover can be sown every fifth year, that sainfoin should not be sown before the ninth year, and lucern not before the tenth. At the South of France, where, under suitable conditions, lucern gives admirable crops, Gasparin long ago dwelt upon the anomalies to which this plant is subject. He was led to believe that it preferred deep-lying richness and opportunity to develop roots continually in new layers of soil that were charged with nutritive matters. On sowing it for the first time on deep soils adequately supplied with moisture, excellent and enduring crops are often obtained with very little manure, or even with no fertilization other than a dressing of land-plaster, while on shallow soils, although it may seem to be doing well at first, it is apt to die off as soon as the roots have reached the subsoil. On irrigated land, or on deep bottom-lands, that are permeable and not too wet, lucern does well, but on upland which has previously borne lucern a new-sown field of it soon begins to die out, and the duration of the field will be limited to a few years, no matter how abundantly the land may be manured.

The length of time necessary in order that a field may again become fit to bear lucern, varies according to the crops which are grown. The time is shortest on irrigated land, and it is not so long on dry fields that are deeply ploughed as on those which are ploughed shallow, and the more permeable a soil is the sooner can lucern be sown upon it. On compact soils, the places where lucern had stood 30 years previously have sometimes been made evident and conspicuous by the inferiority of the new crop and by its lack of endurance.

Olivier de Serres taught in his time that a field of lucern should endure during fifteen years, and Gasparin has seen fields of it come to this age on new land, but ordinarily he found that the crops rarely reached the age of five years, and that it was often ploughed under in its fourth year. Near Nismes, on good, deep land, lucern follows lucern at intervals of 12 years, though it is recognized there that this interval is too short. Gasparin mentions as one hypothesis which has been offered in explanation of the capriciousness of this plant, the idea that the soil may have become charged with hurtful excretions from the crop, and it will be seen that this notion consists very well with what is now known as to the action of the bacteria in the root-nodules of leguminous plants.

In any event, it is seldom wise to try to grow any leguminous plant continuously, though exceptional instances have been reported which show how little is really known about the matter, and indicate that the rule may one day be broken. Thus, Lawes and Gilbert once sowed red clover upon land which had been used as a kitchen garden for several centuries, and which had probably never before borne red clover. The first crops were exceedingly large, and the land sown in 1854 did not require to be resown until 1860. After 36 years it appeared that, although the land usually required to be resown every 2 or 3 years, and the crops had become much smaller than they were at first, still they were quite as good as ordinary farm crops, while the average yield during the 36 years had been nearly 3 long tons of hay to the acre. Cobbett, in his day, reported a case where early peas had been grown on a piece of land every year for more than fifty years; "and if at any time," as he says, "they had been finer than they were every one year of the four or five years that I saw them, they must have been something very extraordinary; for in those years

they were as fine and as full bearing as any that I ever saw in England." Gasparin also mentions several localities in Southern France where peas have been grown habitually, year after year, on the same fields, from time immemorial.

Flax is another crop which grows particularly well on new land; it is said in some localities to require an interval of 3 years, in others 5 or 6 years, and in others 9 years, before it can be grown with success on any given field. But Gasparin had no trouble in growing 8 successive crops of flax on well manured land, and he saw no evidence of exhaustion.

Devices for dispersing Seeds.

That many wild plants have a preference for new land would seem to be shown by the numerous devices which exist in Nature for the dispersion or scattering of seeds. Some seeds drift down the wind to new soils by means of wings or feathers, others are floated away by rains, many cling like burs to passing animals, some are thrown away from the parent plant by the bursting of seed-vessels, while not a few pass undigested through the intestines of birds or beasts which have eaten the fruit or the stems to which the seeds were attached. Moreover, many plants throw out runners, like the strawberry, or side-bulbs, or root-stalks, from which new plants sprout up in due season. (Grant Allen.) It is held, in general, that those wild plants which are best provided with means for dispersion have outrun their competitors in the struggle for existence. It is to be observed, however, that this fact does not necessarily prove that the soil is soon exhausted as to one or another of its chemical constituents by each particular kind of plant, but only that the young plant does well to escape from too close competition with its kindred. It has been well said by Herbert, that plants do not grow where they like best, but where other plants will let them. Hellriegel has shown, withal, that each plant needs its own definite and particular amount of standing-room; and from this circumstance alone it would follow that, as a rule, a new plant will find fewer hindrances and better support in pastures new. Indeed, the proposition is as true of plants as it is of men and animals, that elbow-room is essential to their prosperity, and that crowding is hurtful. Not only do the different individuals in a permanent crowd interfere with each other directly, but harm is apt to follow from the accumulation of their excretions, and of parasites or other enemies. Hence those

species which are provided with appliances for removing their offspring to new or unoccupied land — or rather, as it might be said, to vacant space — are in so far fitted for successful growth and enduring prosperity.

The Plum-tree teaches a Lesson.

One noteworthy example of the significance of "new land" is seen in the behavior of the common plum-tree. It is well known in New England that the plum formerly succeeded perfectly when the country was new, and that it can be grown to-day successfully in the wild forest regions of New Hampshire. The market in Boston is supplied every summer with damsons from Nova Scotia; but in proportion as the country grows older, the plum-trees cease to thrive.

It may possibly be true, as some writers have urged, that the plum-trees have exhausted the soil, and that they really need new land. But there are several facts which militate against this hypothesis. The plum-tree grows perfectly well upon the Continent of Europe, and yields abundant crops of fruit, even upon land that has been the longest cultivated. It does not thrive in the vicinity of Boston, because of the abundance of various and vigorous enemies, both of insect and of vegetable origin. Probably if we coûld but circumvent the curculio and the black-knot fungus (which is peculiar to America), plums might be grown freely enough with the aid of proper manure. But, as things are now, the only economical way of proceeding is to take refuge in the backwoods, and establish the plum-orchards in districts free from those kinds of wild cherry-trees in which the black-knot harbors, and where the curculio is rare.

Fallow Fields.

It must be remembered always, when speaking of rotation, that the natural disintegration and decomposition of matters within the soil tends to counterbalance the exhaustion produced by cropping. Practically, this fact has always been recognized. In many of the older systems of rotation, for example, it was customary to let the land lie fallow every second or third year. Sometimes the fallow fields were left absolutely to themselves, especially if the soil was sandy; but in the better systems of husbandry the land was ploughed frequently, so as to hasten the process of disintegration and nitrification, as well as to destroy weeds, and to turn their constituents to profit as green manure. On the light soils of Nor-

folk (England), it was customary to harrow the fallow fields occasionally, some little time before each of the ploughings, in order that many seeds of weeds might germinate, and that a larger number of young weeds might be turned under by the ploughshare. At the first ploughing, only a shallow furrow was turned, while at the second (cross) ploughing the soil was stirred more deeply. The destruction of insects, also, was sometimes a point of considerable importance. For example, one good way of clearing a field of the pernicious white grubs of the dorbug, or June beetle, is to fallow and work the land thoroughly for a season. Not only will the processes of ploughing and harrowing bring many of the grubs to the surface, there to be devoured by birds, but there will be nothing left for the grubs to feed upon if the land is kept bare of vegetation. It is to be remarked that even now many careful farmers are glad to take action looking to the destruction of weeds, by harrowing or cultivating their land when opportunity offers after one crop has been removed and before another one is to be put in. By tilling the soil frequently in this way, towards the end of summer and during the autumn months, many seeds of weeds are encouraged to germinate, and multitudes of young weeds are buried and destroyed, while many of the last of these growths of weeds are cut off by frost.

Fallowing was commonly practised by the Romans even. In most cases they left the field fallow for a year after taking a crop; though, when manure could be got, they sometimes took two or more crops in succession, and then left the land to lie fallow. The length of time that the fallow fields are left to themselves varies widely in different countries. In poor, wild countries, such as some parts of America, and of Russia also, it is no uncommon thing to take one crop, and then throw the land away, as it were, i. e. leave it without thought of ever using it again. In the Lunenburg heath, in Germany, there are places where the land is regularly burned over every twenty years, and one crop taken from the land. This case might be described as a rotation of 1 grain-crop and 19 fallow fields. In the moorland of North Germany, 1 crop and 12 years of fallow is no uncommon course. These exceptional practices apply, of course, only to very poor land. Indeed, in some parts of Germany, it is customary to distinguish extremely sterile land from that which is simply poor by saying that the one will bring a crop of rye every other year, or once in 3 years, while

the other cannot bear rye oftener than once in 6 or 9 years, as the case may be. In some parts of Spain, two or three fallow years between every two crops are common. So, too, in Durham, in England, many years ago, a "Two Crop and Fallow System" prevailed. The plan was to have two years of fallow succeeded by two years of cropping, the first crop being wheat, and the second oats or beans. But when draining became habitual, and the supply of manure abundant, bare fallows fell out of use, excepting on heavy clays. In some parts of Sweden, the peasants leave half their land fallow every year, while upon the other half they sow grain; and they manure one-seventh of the fallow land every year.

Disintegration in Fallow Fields.

As has been explained in Volume I, at the end of the Chapter on Carbonic Acid, peculiar fermentations may be brought about by the action of micro-organisms in dry, fallow fields; and there can be little question that highly important changes are effected in this way in those countries where there is seldom or never any abundant rain in the summer. It is manifest, however, that disintegration must be going on to some extent during the growth and the tilling of crops. Where land has once been brought into good condition, the amount of this disintegration may every year be sufficient to keep up the supply of mineral matters necessary for the growth of the crop. Upon this idea were founded the horse-hoeing of Tull and the Lois-Weedon system of tillage; and both these methods of cultivation have probably had more or less influence on the arranging of some modern schemes of rotation. The very word "manure," as has been said already, originally meant manœuvre (hand-work), i. e. it meant to dig, to till, to cultivate, and thereby to disintegrate.

The experiments of Lawes and Gilbert bear very forcibly upon this point. Upon a soil described by them as of not more than average wheat-producing quality, which had been under arable cultivation for 2 or 3 centuries, and possibly for a much longer period, they grew wheat continuously, without any manure, for forty and more years in succession. During the 1st ten years the mean annual produce of dressed grain was 15.75 bushels to the acre, during the 2d ten years it was 16.5, during the 3d ten years 12.75, and during the 4th ten years 10.25. The mean annual produce during 40 years was 14 bushels. Before this land was

set apart for the wheat experiments, it had been cropped five times since any manure was put upon it. But, in spite of all this, the soil was in such condition that the amount of matter made available as wheat-food within it, by disintegration and by nitrification, in the course of the year, was sufficient to support crops as large, or almost as large, as the average of those grown in the United States and in several other of the great wheat-growing countries of the world.

Lawes and Gilbert urge that the low rate of produce during the last ten years, as above stated, does not correctly represent the reduction due to mere exhaustion of the soil, for it so happened that unusually bad weather prevailed during this particular term of years. Indeed, under the influence of a rather better season, the crop actually obtained on the very last year of those above mentioned was 13.75 bushels to the acre, or very nearly equal to the average of the 40 crops. The influence of weather was very marked. Thus, in the year 1863, after 19 crops had been taken, 17.25 bushels of wheat were harvested on the unmanured land, while in the worst year only 4.75 bushels were obtained. From all of which they argue that up to a certain period, and excluding variations occasioned by good or bad seasons, the annual decline in produce due to exhaustion may amount to about one-quarter of a bushel of wheat per year and per acre, or to a gross produce of grain and straw of 40 lb. to the acre. With each decline of fertility the rate of reduction becomes less and less, and the soil retains some part of its goodness with a firm grasp.

The average annual produce (grain and straw) removed by these unmanured wheat-crops was one long ton to the acre, or 2,000 lb. of dry substance. From the soil there was taken 100 to 120 lb. of matter to the acre, of which 17 lb. were potash, 10 lb. were phosphoric acid, and 20 lb. nitrogen. So, too, from unmanured plots on a permanent mowing-field, Lawes and Gilbert obtained, on the average of 7 years, 2,800 lb. of hay to the acre. During the last 4 of these years the average annual yield of hay was 2,900 lb. to the acre. On growing potatoes continuously without manure, the average annual yield during the first 4 years was 2 long tons and 13 cwt., during the next 4 years it was 1 ton and 18 cwt., and during the next 4 years it was 1 ton and 8 cwt. For the whole term of 12 years, the mean annual yield was not quite 2 tons per acre.

Natural Strength of Land.

It is to be observed, of course, that this natural process of supplying food could hardly be possible excepting on land fertile enough to be in some sense a reservoir of food. The process of supply and demand cannot here be coincident and equal day by day. The disintegration which occurs in the course of a single summer's day may be wholly insufficient to supply the crop with food on that particular day, and yet, taking the entire year, the disintegration might be largely in excess of what the crop needs or can consume.

This idea of disintegration supplying to the soil what is taken off in the crops, bears directly on what farmers call the "natural strength" of land. There are some soils which, thanks to the incessant action of disintegrating influences upon fit materials, will bear cropping; and there are others that will not, because of the absence of this agency. In wooded districts, such as those not far from Boston on the south shore of Massachusetts Bay, and in the so-called Old Colony, it has long been customary to cut down the trees every 20 or 30 or 40 years, and to allow new forests to grow from the sprouts which shoot up from the old stumps. "Sprout-land" the New Englander calls it. It is known as Coppice in Europe.

It does not appear that there is any great variation from one century to another in the quantity of wood grown upon a given number of acres of the woodland in the course of the 25 or 30 years required to mature the crop. But evidently the conditions of disintegration in the woodland, as well as upon the experimental fields of Lawes and Gilbert, are such that a supply of food is kept up for the use of the crop. The only difference is, that in the woodland the plants seek their food at comparatively great depths and over wide areas, and are so constituted that they can grow slowly and obtain a part of their nitrogen from the air. Hence the soil need not be rich in the beginning, nor the disintegration rapid from year to year. But for the growth of the less robust wheat-plant the conditions must be more favorable.

CHAPTER XXX.

SPECIAL SYSTEMS OF ROTATION.

Why Rotation was first practised.

It should be clearly understood that the practice of rotating crops is not by any means based upon chemical or botanical considerations alone. In so far as this country and Northern Europe are concerned, it seems to be a relic of the time of Village Communities. It is true, indeed, that several noted writers of antiquity held views in regard to rotation which are in accordance with principles now known to be correct. Xenophon speaks of a two years' rotation of wheat and fallow, and Cato and Varro and Virgil tell of the alternate culture of grain and legumes, and there are good reasons for believing with Gasparin that these practices of the ancients were kept up through the middle ages in Italy and other parts of Southern Europe, and that they may have persisted even to the present day in some localities.

But in England and Germany and the other countries of Northern Europe, systems of rotation seem to have been derived directly from the times of village communities, rather than from the Roman civilization. They may be said to be in the main inherited from the "common fields" of village communities, where rotations were made necessary by the system of holding land which prevailed.

In the days when the village, and not the individual, had the management of private affairs, it was customary — instead of having the plough-land partitioned off into separate farms — to let the fields lie open and unenclosed, and to have these fields cultivated by many individuals, each one working for himself upon separate strips of the common tract, i. e. on pieces of land which were allotted to him for a single season. To avoid all conflict of interests, each of the large common fields was marked off into three great parts, one of which parts was devoted, one year in three, to winter grain (i. e. to wheat sown in the autumn, or to rye, in case the land was not fertile enough to bear wheat); another part of the field was devoted to summer grain (barley or oats sown in the spring), while the third part was left fallow. This was the old "three-course" system of rotation, which through many centuries was practised almost universally in the more fertile parts of Europe.

It is evident that, in so far as relates to the use of the separate allotments of grain-land during the growing season, some semblance of the rights of ownership were enjoyed by the householders to whom these strips had been temporarily assigned. There appears, indeed, to have been just enough recognition of the idea of the personal appropriation of land to admit of some private enterprise as to the growing of grain. But it is none the less true that, so long as the system of common unenclosed fields prevailed, it was impossible for any one person to deviate from the established practice; especially as there was usually a common right of pasturage upon the fallow field throughout the year, and upon each of the other fields after harvest. It appears, indeed, that individuals were not allowed to deviate from the established course; and in later times, one of the worst impediments with which the progress of rational agriculture has had to contend has been the tendency of European landlords to compel their tenants to hold fast to established systems of rotation. It has been said, in fact, that no real improvement was introduced into the agriculture of many districts of England until the notion of the perfection of the three-course system was exploded, and tenants were permitted to deviate from it.

Starting in this way from a mere social and physical necessity, the continuance of systems of rotation has always depended in good part upon established customs made rigid by legal forms. In the majority of cases, perhaps, tradition has had more to do with the maintenance of rotations than have any scientific conceptions as to the reason of them, or any just deductions from the results of practical experience.

The Three-course Rotation.

In the original three-course system of Central and Northern Europe, there was usually maintained in connection with the ploughed land, which was given over to grain, a large tract of wild pasture, where cattle, sheep, hogs and geese were tended by herdsmen and shepherds, and there was another tract of permanent meadow, where grass was mown for hay. Where these arrangements existed, it was possible to get dung enough from the cattle and from folding sheep to give the fallow field a dressing of manure; that is to say, the plough-land was manured every third year, since one-third of it was manured each year. But in other instances, where the supply of dung was small, — and this

would naturally be the case as population increased, and the ploughed land came to encroach upon the meadow and pasture, — the common field was divided into twice as many parts as before, and manure was applied only half as often, i. e. every other fallow was dressed with dung, so that the land received manure only once in six years.

Walz has urged that the prejudice still held by many farmers in favor of old, well-rotted manure is a tradition which has been handed down from the time of common fields and the three-course rotation. When every one was obliged to apply the year's stock of manure at an appointed time for one particular crop, much of the manure naturally got to be rotten, and numberless generations of farmers became accustomed to use manure only in that condition. This idea is really supported by the seemingly conflicting statement of Marshall, who, in describing some survivals of the common field husbandry in the Midland counties of England, relates that the manure was commonly carried out immediately from the dung-yard to the field "in a raw, long, strawy state," and that it was ploughed under "without having been previously turned up and digested." This practice, he says, "is probably a dreg of the common field husbandry, in which the yard-manure was perhaps judiciously left unmoved." It is to be noted, however, that Marshall's observation relates to England in 1785, i. e. to a time when and a place where cattle were bedded much more freely with straw than they were upon the German farms to which Walz referred. The statements of both these observers go to show that in the days of common fields comparatively little labor was expended on the forking over of manure. And the fact is not surprising, since the manure was ploughed into fallow land, and there was no thought of harrowing (even after harrows had been invented) until several months after the application of the manure.

The three-course system is commended by its great regularity and simplicity, and by the possibility of cultivating land in a wholesale way at small cost for supervision and labor, and is upon the whole not ill-adapted for a primitive state of society. It is manifestly incompatible, however, with the existence of a dense population, and would not be advantageous for a scattered population living upon separate farms. Excepting in fertile regions, the two grain-crops in succession might sap the soil unduly, and

they would naturally favor not a little the growth of many pernicious weeds; though it must be admitted that actually the weeds were kept somewhat in check by sheep and other animals which were pastured upon the stubble-fields, and that these animals were in some part supported by the weeds. The growing of spring grain rather than winter grain in the second year was probably necessitated in many regions by the short seasons, which did not allow time enough after the harvest for preparing all the land to be sown with winter wheat. So, too, the fallow field was a convenience, in that it gave plenty of time for applying manure, and for preparing the land for the autumnal seeding.

As a matter of course, no fences were needed so long as all animals were herded on outlying wild land. The vast amount of labor expended formerly by the farmers of New England in building stone-walls, even on very poor land, points to a revulsion of feeling against the older system of holding land in common, and goes to show how important the owning of land was thought to be by our ancestors, and how ignorant they were as to the real abundance of land on this continent, or rather in respect to the ability of the white man to occupy land at a little distance from the sea.

Derivation of other Systems from the Three-course Plan.

As regards the derivation of other systems of rotation from the old three-course plan, it may be conceived that, as population and the consequent demand for grain increased, the pastures in fertile districts were gradually ploughed up and converted into arable land, and that, as a consequence, comparatively few cattle could be supported. Hence, so little manure was obtained that the crops suffered, the land was after a while run out, and emigration became necessary. But on being left to itself, the land soon reverted naturally to the state of pasture, cattle were again kept, and dung was again produced. To maintain the cattle, the significance of which as producers of dung and flesh was now apparent, regular fields of sown grass were established.

Grass Rotations.

As would naturally be expected, the introduction of grass into the regular system of rotation first appeared in countries moist enough to be specially fitted for grazing. It seems to have been first practised extensively in Holstein and Mecklenburg, and it soon raised these countries to a high place among the agricultural

nations. It has been employed in Scotland also, and in the Midland counties of England since a very early period. It is not improbable that the numerous small enclosed fields, hedges and hedge-rows which prevail in certain parts of England were first established when the three-field rotation was changed to an alternation between grain and grass. It is to be noted, however, that in more recent times clover has often been grown in rotations, either instead of grass or in conjunction with it. Thus, in Norfolk County (England), as will be explained directly, fields of mixed clover and ray-grass have long been esteemed.

The idea of the grass rotation is simply to have fields of artificial pasture (maintained for several years) alternate with grain. The system has been found to answer exceedingly well, not only in the localities just mentioned, but in various others where the climate is so moist that grass grows freely and unchecked by drought, and where the land is so free from stones that most of it can be brought under the plough. It is practised, for example, upon the rainy uplands of Bavaria and Saxony, as well as in the lowlands of the North of Germany and Denmark. There are many varieties of this system of grass rotation. Thus, in Holstein, one way is: 1, oats on the newly-broken grass land; 2, a fallow to destroy grass and weeds; 3, wheat, with or without manure, according to the state of the land; 4, barley; 5, rye, lightly manured; 6, oats with clover; 7 and 8, pasture.

An old Scotch rotation was: fallow; wheat; grass, fed for one, two, or three years; then oats, peas, or beans, and wheat again. A simpler system, followed in the Styrian uplands, is: 1, summer rye, with manure; 2, oats; 3, winter rye, with manure; 4, 5, and 6, grass land. This last has a certain resemblance to a course not unusual in the vicinity of Boston, viz.: 1, grass for mowing, kept down for six or eight years, or as long as the grass continues to give a fair yield; 2, winter rye, on the inverted sod, without manure; 3, Indian corn, potatoes, or sometimes roots, i. e. a hoed crop, well manured; 4, seed down to grass again, with rye, unless the land is so foul that another year of cultivation is needed to destroy the weeds.

It is to be noticed, however, that there are very considerable differences between the plans of seeding down for pasturage in a rotation and of seeding down for hay-fields. The original grass rotations which have played so important a part in the history of

European agriculture, appear to have been based for the most part on the idea of obtaining pasturage for sheep or for cattle. Hence, the kinds of seeds sown, and the methods of procedure followed, were commonly different from those employed in this country. A common course in Western New York is said to be: 1, Indian corn on sod, with manure; 2, barley or oats; 3, wheat; 4, clover, mown first for hay, and afterwards for seed; 5, clover and timothy, mown for hay. Another course, practised in the Northern part of New York, is: 1, oats on sod-land; 2, part Indian corn, part potatoes, and part roots: 3, barley or spring wheat; 4, 5, and 6, clover or grass, i. e. timothy. An old system, employed in the Midland Counties of England, was: 1, oats on the sod; 2, wheat; 3, barley sown with grass; 4, pasture for 7 or 8 years.

Rotations in New England.

Not many definite rotations have ever been established in New England. For a long time after the settlement of this country, Indian corn and rye seem to have been grown continually in alternation one with the other, as the principal if not the only crops. Perhaps the only deviation at one time from this practice was the occasional cultivation of a field of flax. The potato was not introduced into New England until 1719, and the cultivation of it did not become general until after a particularly inclement year (1756) had ruined the crops of corn and rye, and caused an alarming scarcity of food. In Germany, also, it was a famine in 1770 which led to the general cultivation of the potato in that country. One old rotation, commended for heavy land, was: 1, oats; 2, potatoes, well dunged; 3, flax or wheat; 4, grass, for as many years as possible. General Washington, writing of the western end of Long Island, in 1790, says: Their general mode of cropping is: 1, Indian corn upon a lay, manured in the hill, half a shovelful in each hole, though some scatter the dung over the field equally; 2, oats and flax; 3, wheat, with what manure they can spare from the Indian corn land. With the wheat, or on it, towards the close of the snows, they sow clover, from 4 to 6 lb., and a quart of timothy seed. This lays from 3 to 6 years, according as the grass remains, or as the condition of the ground is; for, as soon as they find it beginning to bind, they plough.

In some parts of Pennsylvania, a system of rotation prevails

which consists essentially of maize, winter wheat, and mixed grass and clover, though several modifications of it have been described. Thus the older plan was: 1, maize, manured on the sod, which was ploughed under in the spring; 2, oats, without any manure; 3, winter wheat (and grass), usually dressed with 10 or 12 loads of barnyard-manure. Timothy-seed was sown at the same time as the wheat, and clover seed the next spring. The grass was mown for two years at least, or as long as remunerative crops can be taken, though the clover usually disappears in good part after the second year. One variety of this rotation is: 1, maize; 2, part wheat, part tobacco, and part oats (or sometimes maize); 3, wheat, with grass and clover; 4, hay; 5, pasture. A more modern variation is: 1, maize, manured; 2, part tobacco and part maize; manure is applied in this second year as well as in the first, and the tobacco often gets a dressing of superphosphate; 3, winter wheat; 4, winter wheat, with timothy seed, and clover sown in the next spring; not infrequently 200 or 300 lb. to the acre of superphosphate are applied to the wheat, and a part of the land may be devoted to oats and potatoes in the 3d and 4th years; 5, and 6, clover and grass, mown for hay and subsequently pastured.

Mr. Mitchell has suggested for New England: 1, maize, cut young for fodder, the earlier cuttings being followed by turnips; 2, part carrots, part mangolds, and part potatoes; 3, oats or other cereal; 4, clover and grass, to be kept down as long as possible. For soiling cows, in summer, he suggests pasture grass from May 10 to June 10; then mown winter rye; then lucern; then clover and orchard grass; then fodder corn; and, finally, late-sown barley and the leaves of root-crops, which, as will be seen, would involve a tolerably complex arrangement of crops.

An Alabama rotation is: 1, Indian corn; 2, wheat; 3 and 4, cotton; 5 and 6, clover.

Some readable speculations on one of the old varieties of grass rotation, as practised in the Roman Campagna, may be found in the second volume of Mr. George S. Hillard's "Six Months in Italy."

At the present day, the old grass system, such as has here been described, would be intolerable in any country other than one in which, from excessive moisture or mediocre soil, is forced to devote itself to the business of grazing. The chief advantage of the

system is found in the fact that the land can be kept in fair condition with a comparatively small expenditure of labor, and in passably good case withal, through the droppings of the cattle which are pastured or fed upon it, and that when the pasture is to be broken up and made ready for grain, ample time is afforded for the processes of preparation. Grass rotations are suitable enough in many localities for farmers who have little or no capital, but it is impossible in this way to work good land to its utmost capacity.

Pasturing good Land refreshes it.

From the chemical point of view, the significance of the introduction of grass-land into courses of rotation is that in moist climates the pastured grass, far from exhausting the soil, actually improves it. A grass-field is, to all intents and purposes, a dwarf forest. If the grass or the trees are allowed to die and rot upon the land, the soil will become richer every year, because the roots of the plants bring up new stores of food from below to be deposited upon the surface, and some kinds of the plants are supplied with nitrogen from the air, while the mat of grass-sod, or of tree-roots, and the litter beneath the trees, shield the humus from oxidation, and prevent the finer portions of the soil from being washed away by rain. In the same way, land will improve when fatting cattle are pastured upon it; for the cattle that eat the grass restore to the soil all but a minute fraction of the mineral matters contained in their food, and a large proportion of the nitrogen also is put to profit by the grass.

Moreover, when the grass is mown to be fed out upon the farm, either green or in the form of hay, the better part of the dung and urine will practically be carried back to the land. Consequently, the adoption of grass rotations in place of the three-course plan was a distinct gain for the land in all cases where the supply of manure obtained from outlying grass-lands, i. e. natural pastures and meadows, was insufficient to dress the ploughed fields. Even in this country it is argued often enough that land is "at rest" when it is in grass. In many localities, as soon as a cultivated field shows signs of deterioration and begins to yield unsatisfactory crops of Indian corn or of grain, it is customary to seed it down to grass and clover and to leave the land lying in grass during several years as a means of recuperation.

It should be clearly understood that the grass system is still

retained in several fertile countries, subject, however, to certain modifications. Thus, for example, in some parts of Saxony to-day, the course is: 1, winter rye, with manure on the inverted sod; 2, potatoes; 3, wheat; 4, clover; 5, oats; 6, peas, beans, or vetches, with dung; 7, winter rye; 8, white clover with grass; 9 and 10, pasture. Or: 1, potatoes on the sod, with manure; 2, rye; 3, flax; 4, wheat; 5, oats; 6, vetches; 7, 8, and 9, pasture.

A five-course rotation, known as the Berwickshire course, has long been popular in the North of England and in Scotland. It consists of: 1, wheat or oats; 2, turnips or other roots; 3, barley or oats; and 4 and 5, clover and grass. Sometimes this system is changed to a course of six years, by taking two grain crops in succession after the grass. This plan is said to answer very well on strong, stiff clay soils, and as the second grain crop usually receives a light dressing of artificial fertilizers, it often does better than the first crop. In other localities, the grass is kept down during three or four years instead of two, and in this way the course becomes one of 6 or of 7 shifts, as the case may be. On heavy clays, either 4 or 6 shifts are thought to be better than 5; and it is said that the grain crop which succeeds the grass is better when the grass has been kept down during three years instead of two. Indeed, two grain crops in succession are often grown after the three years of grass. This five-course rotation has the merit that the grain-fields can be kept comparatively free from weeds, and that a heavy crop of grain is taken on the land which has been cleaned and well manured for the turnips. By feeding out the straw of the grain crops in conjunction with the turnips, many cattle can be wintered, while the aftermath of the fourth year and the grass-field of the fifth year afford summer pasturage.

Grass Rotations near Edinburgh.

The following rotations are practised to-day on farms not far from Edinburgh, the increasing demand for meat and the increasing cost of labor tending both to keep up and to increase the grass system of husbandry in the moist climate of Scotland: 1, oats; 2, part potatoes and part beans; 3, wheat; 4, turnips; 5, barley; 6, hay or pasture. Many farmers who have practised this course are said to incline more and more to two years of pasture instead of one, as stated. Other farmers prefer: 1, oats; 2, part pota-

toes and part turnips; 3, barley or wheat; 4, hay; 5, pasture. Others still have: 1, oats; 2, beans; 3, wheat; 4, turnips; 5, barley; 6, grass.

Farther from Edinburgh they have: 1, oats; 2, part potatoes and part turnips; 3, wheat or barley; 4, hay and grass; 5, grass. Or on lighter land: 1, oats or wheat; 2, turnips; 3, barley; 4, 5, and 6, grass. One great merit of the oat-crop in these rotations is that it smothers grass and checks the growth of young weeds, so that the land is finally left in a much cleaner condition than would have been the case if wheat had been grown upon it. Were it not for the difficulty of keeping the land clean in that moist climate, a crop of wheat of nearly double the value of the oat-crop might be grown in the oats' place. (Russell.)

The following example is cited in illustration of the comparative facility with which grass rotations may be practised under a favoring climate. In Lincolnshire, England, on a sandy, silty loam of poor quality, a farmer is said to have habitually laid down his fields to grass as follows: During the spring and early summer the land was cleaned and well worked until the end of July, to obtain a fine tilth; and a mixture of 3 bushels of ray-grass-seed, 14 lb. of white clover-seed, and 2 lb. of parsley-seed, to the acre was then sown. In September the grass was found to be forward enough for the admission of sheep, a moderate number of which were turned in upon it for a few weeks. The land was left to itself during winter, and in the spring from 10 to 16 sheep to the acre were pastured upon it, and sent fat to market during the summer. A slight dressing of dung was strewn upon the land in the second winter, and sheep were fattened as before during the following summer, until the sward was broken up. The contrast between a rich grazing ground like this and a poor natural pasture is strongly marked.

Rotation and Labor.

The idea of these improved systems of rotation, as of all the courses which have been adopted in the high farming of modern times, is to get from the land, in a given time, as many merchantable products as can possibly be obtained by the judicious expenditure of labor and capital. This remark suggests a point which has not been sufficiently discussed hitherto, viz. the judicious division and adjustment of labor upon the farm. Manifestly this consideration, in the absence of our modern machinery, must formerly

have had a very important bearing upon the practice of rotation. In the old days of hand labor, the remark applied to all farms,—as it it does still to farms devoted to several kinds of crops,—that the crops must be so arranged that the whole labor of seed-time shall not come at once; and that the times of ripening of the crops shall be different, in order to secure a succession of harvests. It was essential to know about how many days of labor would be required, and at what times, for putting in and taking off each crop, in order that no one crop in the rotation should interfere with the proper treatment of the others.

It was a great point with the farmers to divide their labor so that it should be distributed as evenly as possible through the entire season. Thus, in the old three-field husbandry of the village communities, the labor of preparing the land for barley or oats in the spring, and the sowing of these crops, preceded the hauling out to the fallow field of the year's stock of manure, and the ploughing in of this manure; while the operations of preparing for and sowing the wheat came on only in late summer or early autumn, after the hay and the grain-crops had been harvested.

A somewhat similar remark would be true of all the earlier systems of rotation, but when machinery came in to relieve the farmer, the old systems of rotation had to be modified, in order that the machines might be worked to the best advantage. In this sense, Mr. Mechi has expressed his conviction that the old English four-course rotation must give way, especially on heavy lands, to a freer system. Under the old plan of ploughing with horses, and in the lack of artificial fertilizers, such a system was very well adapted to the circumstances, the horse-work being regularly diffused or apportioned over the whole year. But now that the land can be cultivated by means of steam-ploughs, and manured with chemicals, the case is greatly altered. By using steam-ploughs, the stubble fields can be broken up, and the winter crops got in with a rapidity formerly unknown; and so with other operations, such as threshing and harvesting.

Adjustment of Crops to Labor.

Even in the days of the old three-course rotation, the area of land which could be sown to grain would necessarily depend in some measure on the number of men and animals available for preparing the land at the appropriate seasons. But after the time of sowing grain had passed by, and manure had been hauled to

the fallow land, there must have been an abundance of labor for planting that land with some kind of a crop, if only a suitable crop had been within reach. When turnips came to be grown on the light loams of Norfolk (England) it was accounted an advantage that their seeds were sown so late in the season that the labor of putting in the crop did not interfere with the sowing of grain. But the frequency of summer showers in that region permitted the growing of turnips in a manner which might hardly be practicable in many other, drier, countries, unless it were on low-lying land.

On dairy farms in England, where grass is the staple product, it was recognized long ago that the plan of rotation need not be adhered to so strictly and carefully as on arable farms, for the horse and hand labor of the dairy farm may be concentrated on occasion upon the limited area of ploughed land, while on an arable farm any small irregularity in the system of cropping might interfere with the proper adjustment of labor.

In considering the judicious distribution of labor, it is well to keep in view the influence which one or another crop may exert in cleansing the land, or fouling it by encouraging the growth of weeds; for it is important in many cases that time enough shall be allowed for the application of some cleansing cultivation between the harvesting of one crop and the sowing of its successor.

Among the manifold merits of Indian corn may be mentioned the fact that this crop is sown and harvested at other times and seasons than the cereal grains. Thus it happens that the American farmer is enabled to expend his labor to great advantage. Every year he can grow two kinds of bread-crops, and produce a large amount of human food, because the work of sowing and gathering his corn does not interfere with the seeding and harvesting of his grain.

As another example of the influence of labor on the conduct of rotations, it may be said that there was formerly a certain incentive to grow rye in the immediate vicinity of Boston, because the long straw could be sold readily at a high price; and the question naturally arises, Why did not all the suburban farmers grow rye? The answer is, that there is small profit in growing this crop unless the other crops of the farm, and the farm work, have been adjusted to this particular line of business. In case the farm has much hay to be made, the rye harvest would fall at an incon-

venient season, and interfere with haying. Labor has to be expended in threshing the rye, and perhaps in rehandling the straw after threshing and before selling it. And then again, when sown with grass, the rye saps the land at the very time when it is desirable that the growth of the grass shall be particularly favored. Hence, if the farmer wishes to grow rye, he must cut and contrive accordingly; and so it is, of course, with every other crop. It has been repeatedly remarked by practical men, that, for large-way farmers, maize ensilage will be profitable only in those cases where the getting of it and the use of it do not conflict with the general plan of the farm, and with the utilization of unmerchantable products which are obtained upon the farm.

Other Green Crops than Grass.

Another way of meeting the lack of manure in the three-course system was to have more frequent fallows, which was at last tantamount to adopting a two-course rotation, viz.: 1, grain; 2, fallow. Possibly there may be situations even now where this plan would be the more economical, all things considered, though the idea on which it rests can hardly be regarded as philosophical.

Doubtless one of the reasons why bare fallows were resorted to by the forefathers was the scantiness of their list of agricultural plants. Probably at one time no field-crops were known in Northern Europe beside grain and grass. Although in Southern countries — as in Italy, Egypt and Spain, and Eastern Asia — beans and other leguminous crops have from time immemorial been an important source of human food, they seem to have been grown much more sparingly, and as garden plants, at the North. The presumption is that only small patches of them were grown at first, and that the cultivation of beans in a wholesale way, in Northern Europe, was at one time by no means generally practised. The introduction of this crop upon the fallow field in the third year, on suitable soils, seems to have been of the nature of a discovery and innovation, and it is known that the introduction of turnips, clover, potatoes, and maize, not to mention sugar-beets, has greatly changed the agriculture of several European nations.

It has been said that the famines which formerly devastated Europe became much less frequent after the potato was cultivated as a field-crop. Before the introduction of the potato it happened

constantly, every six or eight years, that somewhere on the Continent of Europe the inhabitants of large tracts of country suffered from dearth because their grain-crops had failed. It is to be noted that this statement is not in the least invalidated by the Irish famine of 1846, for the trouble in that country was that the people had placed too much dependence on that one crop. In point of fact, nothing illustrates more clearly the value of the potato as a food-producing plant than the previous experience with it in Ireland, where, thanks to this single plant, the population increased from 3,000,000 soon after the middle of the 18th century to something more than 8,250,000 in 1845, i. e. just before the famine of 1846.

Previous to the introduction of turnips, beets, potatoes, and other plants which could be grown in alternation with grain, and in the light of the experience which had taught that grain could not well be grown continually with the methods of manuring employed in those days, a respite from grain led naturally to the bare fallow field. It was of the nature of a revolution in agriculture when the facts became known that clover could be sown with the grain, in the spring of the second year, and usefully occupy the land during the following or fallow year, to produce a large quantity of excellent fodder, to smother many kinds of weeds, and actually to contribute to the fertility of the soil.

Green Crops should replace Fallows.

Manifestly, it would usually be better nowadays to substitute some kind of green crop for the bare fallow. The poorer the land, the greater the need of the green crop; for it might then be ploughed under as manure, or, in default of labor to do that, it might be left to rot upon the surface of the ground; or it might be mown and fed to cattle upon the ground, or be pastured outright. In most cases, however, it will not be necessary thus to sacrifice the green crop; for the latter not only feeds upon the land in a different way from grain, and does not exhaust it like grain, but in many instances it actually tends to refresh the soil, and to make it fit for producing a new crop of grain. A case in point was the use of rape (coleseed) in English husbandry as practised at least two hundred years ago. Instead of leaving the fallow field bare, rape-seed was sometimes sown upon it in midsummer, and sheep were turned in in late autumn to eat off the green crop. The land was thus freed from weeds, and was ferti-

lized by the sheep, and it gave great crops of oats or of barley the next year. (Houghton.) So too in some of the grain-growing districts of Europe, it was customary long ago to grow vetches on the stubble as a fodder-crop, whereby weeds were smothered and kept down, and (as we now know) nitrogen was brought to the land from the air. The interpolation of hoed crops was equally important, for, beside mitigating the rankness of the manure, the process of cultivating them destroyed vast numbers of weeds and so cleaned the land.

The discovery that crops may be grown on the fallow field was of immense importance for the progress of civilization, not only by enabling the farmer to keep more animals and obtain more milk and meat, but in the case of edible plants like the potato, as was just now said, the risk of a total failure of food-crops in any given year was greatly diminished. In so far as concerns the disintegration of mineral matters, it is probable enough that the process may be more rapid when the soil is covered with vegetation than when it has been left bare. Disintegration may be more rapid and thorough, for example, in a clover-field than in a fallow field. With regard to nitrification, it is to be noted that, although no inconsiderable quantities of nitrates are actually formed in bare fallow fields, the amount thus produced is ordinarily hardly large enough to justify the leaving of good land idle in any locality where it might be put to profitable use.

The objections to a green crop in place of the bare fallow are that it is apt to be in the way, and so prevent the early sowing of the winter grain, and that it may take out from the soil both water and nitrates so completely that the young grain-plants may fail to get so well started as they would have done in case the land had been left bare. But, as regards leguminous crops at least, these objections are commonly overborne by the great improvement in the condition of the soil which is brought about by the green crop, especially in that it leaves a great store of useful nitrogen in the land. Moreover, in wet countries, and especially on heavy land, there is sometimes a great advantage in having a clover or grass sod growing on fields which are to be sown with wheat in the autumn, such as would formerly have been left bare; for manure can readily be hauled upon the sod-land and distributed in spite of frequent rains, which will do good rather than harm, in that they cause the soluble constituents of the manure to soak into the

soil equably. Finally, there will always be found opportunity to plough, harrow, and sow the sod-land, no matter how wet the season. (Marshall.)

Salable Products from Fallow-crops.

In the beginning, fallow-crops were grown in order to get fodder from which to obtain animals and animal products and manure, and very extensive use was made in this sense of turnips and the clovers and allied plants. In some European localities, mangolds, cabbages, potatoes, and maize were grown to this end, though, considered as mere fodder-crops, neither of these plants could there compete with turnips and the clovers. Subsequently, some of these plants were grown for their own sakes, as sources of merchantable products, and this fact has had great influence in the development of modern agriculture. Thus potatoes acquired great importance in Europe as a source of starch, alcohol, and sugar (glucose), very much in the same way that Indian corn is important in this country as a source of these substances. Enormous quantities of beets also are grown there as a source of sugar; and it is accounted a great merit of these crops that the residues from the manufactured articles are valuable for feeding animals. At one time rape was grown very freely, and its seeds furnished both lamp-oil and oil-cake.

The advantage of putting land to constant use whenever possible hardly needs to be alluded to. Houghton said upon this point, in 1693: "I observe that every third year is lost in common fields, and so is a good part of the second; for in enclosures good husbandmen do have after their beans, peas, oats, or barley [of the second year], a crop of turnips, clover, or something else." It must be said, however, that in many regions the farmers, through mere force of circumstances, are compelled to leave some portions of their land fallow and bare. Thus, upon farms in some of the more remote clay districts of England, where the roads and the farm lanes are practically impassable during many weeks of the year, only a part of the land not in grain can profitably be devoted to root-crops because of the great difficulty of handling these crops. In some instances it is said that the most profitable course has been found in leaving bare as much as two-thirds of the land not in grain, while roots are grown upon the other third.

As illustrating this point, it may here be said that the systematic

growing of crops on the fallow field seems to have first been practised in Flanders and Venice, when the commercial prosperity of these countries made them populous and powerful enough to maintain some semblance of tranquillity. It is known that at Venice, in the 16th century, the old Roman fallow of the second year had been given up and that it was then a common practice to grow wheat, millet, and beans in succession, in such wise that the rotation might be stated as follows: 1, wheat, followed by buckwheat or millet as a stolen crop; 2, a legume or millet. It is said, indeed, that this rotation has persisted to the present day, with the modification that the millet of the second year had been replaced by tall southern maize, and that in place of the stolen millet of the first year, a crop of a small, early variety of maize has been substituted.

It is interesting to remark how differently Indian corn was managed in the more sparsely settled region of Hungary when it was first introduced into that country from Turkey (in 1611). There it came in contact with the three-course rotation, and was substituted for the spring grain of the second year. Very great advantage was gained in this way, for maize is a much more productive crop than oats or barley, and it was found that it yielded at least 30-fold where the spring grain had yielded no more than 10-fold. A common rotation in some parts of Hungary, even as late as the early part of this century, was: 1, winter wheat or rye; 2, spring grain, or maize; 3, fallow; 4, winter grain; 5, spring grain; 6, fallow, well manured; i. e. there was a simple fallow every third year, and a manured fallow every sixth year.

Nitrates are supplied by the Refuse of Crops.

The significance of the roots, stubble and waste leaves which remain in or upon the ground whence a green crop has been taken has been illustrated by experiments of Lawes and Gilbert, who insist that the residual organic matter left in the soil by crops and by weeds constitutes the chief material from which nitrates are produced. Even grain stubble is important as a source of nitrates. Thus, on one of their fields where wheat had been grown continuously during thirty years, they observed the facts which are set forth in the following table of averages: —

Kind of Manure.	Lb. Total Crop (Grain and Straw).	Amount of Nitrate-nitrogen in 1,000 Parts of Soil.	Proportion of Nitrate-nitrogen formed in Soil for each 1,000 Parts of Crop.
No manure	2,168	6.7	7.6
200 lb. ammonium salts and mixture of minerals . .	3,954	10.2	7.3
400 lb. ammonium salts and mixture of minerals . .	5,710	12.9	7.0
600 lb. ammonium salts and mixture of minerals . .	6,778	13.3	6.3
550 lb. nitrate of soda and mixture of minerals . .	6,903	12.4	5.5
550 lb. nitrate of soda . .	4,293	19.9	12.6
14 tons farmyard-manure .	5,696	11.4	9.4

The similarity of the first three items in the last column of figures, viz. that the average crop produced during 30 years stands to the average amount of nitrate-nitrogen formed in the soil as 1,000 : 7.6, 7.3, and 7 respectively, is not a little remarkable in view of the great differences between the absolute amounts of crops produced in the three instances. It would seem that the capacity of the soil for producing nitrates increased according as the crops increased. Lawes and Gilbert have drawn from these results the following conclusion: "In fact, the crop-residue annually left in the soil constitutes in most cases the chief material out of which nitrates are produced. Recent crop-residues are not, however, in any case the sole source of soil-nitrates. If this were so, the figures above cited would be in all cases identical, while in fact the proportion of nitrate-nitrogen decreases somewhat with each additional increment of crop. The nitrates produced are derived partly from the old nitrogenous capital of the soil, and partly from comparatively recent crop-residues. In the case of the unmanured plots, the influence of the old nitrogenous capital of the soil is shown to the largest extent, while on the plots of heaviest produce, i. e. those most heavily manured with nitrate of soda and with ammonium salts, it has least influence. On the plots fertilized with farmyard-manure and with nitrate of soda there was, of course, a considerable source of nitrates over and above the crop-residue."

Fallows may Improve Tilth, or Injure It.

There can be little doubt either that fallows were often resorted to formerly as a means of keeping land in good tilth, or that on some soils they may be less helpful for tilth than green crops. Before the use of steam-ploughs, it was urged by some European

writers, that on certain stiff, strong clays occasional bare fallows are wellnigh essential in order that the land may be kept in good condition; for such land is apt to be puddled when it is tilled at improper moments, and there must be a limit on every farm to the amount of ploughing which can be done by men and teams in any single week or fortnight of good weather. On many a clayey soil the old English plan of ploughing under long manure late in the spring, on fields which were to be left fallow until the autumn, must have been better policy than any attempt to plough or to haul out manure when the land was wet. From facts which have been set forth, under the head of Tillage, relating to the danger of puddling clays by working them at improper seasons, it is evident that fallows were often esteemed as a means of preserving tilth; and it is also evident that their importance was greatly diminished by the introduction of improvements such as liming and draining. On the other hand, it is equally true — where the farmer has the means of ploughing all his land just when he pleases — that the tilth of many clays may be improved by ploughing under occasionally a grass-sod, or a clover-sod, as will be insisted on a subsequent page.

Other writers have insisted that, in localities where clover will not grow, it is much better to have bare fallows occasionally than it would be to continue to grow crops incessantly, in case there is not enough manure at one's disposal to keep the land in a proper state of fermentation; for, by the excessive cropping, poor land would speedily be "run out," i. e. it would become hard, "sour," and "out of condition." In short, there would result a state of affairs not easily to be explained in our present ignorance of the more delicate chemistry or mycology of the soil, but sufficiently well known to practical men as a danger to be avoided. Indeed, if the cropping were pushed too far, the final barrenness of the land induced by the scourging might perhaps necessitate a period of rest much longer than the aggregate of all the bare fallows which, if judiciously interpolated, could have saved the soil from any extreme injury.

Former Importance of Grain-crops.

It should always be remembered that, until a comparatively recent period, i. e. before easy methods of transportation had been put in practice, the chief problem of European agriculture in almost every locality was how to produce the largest amount of

breadstuffs to be used as human food. When Arthur Young travelled in France, towards the close of the last century, and sought to convince the farmers that some of their practices might be improved, he was met by the inquiry whether his proposed innovations might not interfere with the growing of wheat, which was for them the most important crop. Indeed, it was maintained long ago, in some parts of Europe, that—excepting the clover rotations, which would be esteemed everywhere were it not for the circumstance that clover is apt to be an uncertain crop—more grain could be got, generally speaking, by resorting to systems of rotation which include bare fallows, than by interpolating such green or fallow crops as peas, beans, or vetches. Before the discovery that nitrogen can be got from the air by the symbiotic bacteria, it was thought by some farmers that the merit of the green crops was, not that a larger yield of the cereal grains could be got by means of them in a given term of years, but that they produced a larger amount of useful products of all kinds, and in the aggregate, without much diminution of the yield of grain. More manure can be got from them also. It is to be insisted, withal, that while in some regions adequately supplied with moisture all kinds of leguminous crops may have great merit as promoters of fertility and good tilth, they may nevertheless do harm in other localities by abstracting too much moisture from the land, as will be explained directly.

Fallow Fields apt to be gullied by Rain.

In many countries, like several of our Southern States, where those grasses which form a thick mat of sod do not thrive, and where heavy showers of rain are frequent, there is one fundamental objection to the leaving of land bare, especially if it be frequently tilled, in that rains are apt to wash away the soil bodily, and winds to blow it away. It is by causing such waste as this that careless systems of agriculture tend to destroy a country, and it is by preventing it that forests and prairies preserve the fertility of the land.

The denuding action of rain is specially harmful in regions where light friable loams repose on impermeable or difficultly permeable clays. Under such conditions, whenever the surface soil of a bare sloping field is suddenly surcharged with water by a heavy fall of rain, which cannot soak downward into the subsoil, it happens that the excess of water bursts out and flows away in

muddy torrents, which sweep off vast quantities of the most fertile portions of the land. On steep hillsides, it will usually be well so to arrange the courses of crops that the risk of washing the land shall be made as small as possible. As a general rule, it will be better to break up such land in the spring rather than in the autumn, and to strive to have a crop of grain or grass established upon the field before the next winter. It will be best to leave sod-land or even stubble-fields to stand untouched through the winter. Moreover, when ploughing must be done in the autumn, it is to be remembered that a heavy inverted sod will be less apt to suffer from washing than recently broken stubble-land would be.

Countries rich in ancient times and now barren have become so either through denudation by rain, or from an actual want of water caused by a diminution of the rain-fall. There is no reason to believe that any considerable amount of land naturally even moderately fertile has ever been permanently exhausted by taking crops from it, though there are numerous instances in districts of light loamy soils lying on compact subsoils where irreparable injury has been done by the scouring action of rains.

Justification of Fallows.

Probably there are but three considerations, other than those relating to the prices of labor and land, and to tillage, as was just now said, that can really justify bare fallows; viz., the opportunity afforded to accumulate a store of nitrates in the land for the coming crop; to clear foul land from some kinds of weeds; and the fact that in dry climates fallow land is less likely to suffer from drought in the autumn, at the time for sowing grain, than land from which moisture has been taken all summer by a leafy green crop. In any event, the absence of any crop to hinder the sowing of winter grain as early as may seem fit is clearly an advantage, in that time enough may be allowed for the crop to get well established during the autumn months, and fitted to withstand the severe weather of winter. But early sowing would be impracticable upon land from which a leafy green crop had pumped out the water so thoroughly that not enough moisture was left to permit the seed-grain to germinate. It is hardly conceivable that the two-course rotation can have been established for the sake of killing weeds, though it is not unlikely that it may have been esteemed both for supplying nitrates and as a safeguard against drought.

It is noteworthy that in some of the wheat-growing Western States much land has to be left fallow occasionally when a persistent drought at the close of the summer puts the soil into such a condition that it cannot be ploughed. So, too, in regions where there is scant time after the grain harvest to prepare the land for the next crop, it may sometimes happen that a field has to be left fallow because a particularly unfavorable season has prevented the farmer from seeding as much land as he wished to sow. (Oetken.)

Leafy Crops dry out the Soil.

In cases where winter grain has failed to grow well upon land from which a leafy crop like vetches has just been taken, it has been suggested repeatedly by practical men that the real trouble may be that the vetches have dried out the soil too completely, and several scientific writers have insisted that this supposition is correct. It has been noticed also in the sandy part of Norfolk County, England, that while turnips generally succeed well after rye that has been sown for sheep-feed, they seldom thrive after vetches. "A heavy crop of vetches seems to extract every drop of moisture from this thirsty soil, and the turnip-plant is invariably a failure." The amount of water transpired by growing plants is so enormous that a real justification for bare fallows in dry climates is found in the fact that a vigorous crop of any free-growing leafy plant might pump the soil so nearly dry that not enough moisture would be left to start a wheat-crop, although there might have been an ample supply of water in early autumn in that same land, provided nothing had been allowed to grow upon it.

Many elaborate experiments have been made by Wilhelm to test the influence of living plants and that of tillage on the amount of moisture in the soil, and a few of his results are given in the following tables. He examined, even in late winter, soils from fields on which different kinds of crops had been grown during the previous year, and in a deep loam, rich in humus, he found the following percentage amounts of moisture: —

At a Depth of Feet.	In the fresh Earth of a Maize Field.	Lucern Field.	Calculated on the dry Earth. Maize Field.	Lucern Field.
½	22.2	17.7	28.5	21.4
1½	16.9	13.2	20.3	15.2
2½	16.4	12.2	19.7	13.9

In a marly, sandy loam, overlying pure moist sand, he found, —

At a Depth of Feet.	In the fresh Earth of a Wheat Field.	In the fresh Earth of a Beet Field.	Calculated on the dry Earth. Wheat Field.	Calculated on the dry Earth. Beet Field.
½	18.84	16.92	23.22	20.37
1½	20.81	18.01	26.28	21.96
2½	24.26	21.61	32.03	27.57

In both cases, the fields which had been longest covered with growing crops (lucern and beets) contained less moisture than the others. It will be noticed also how the deep-rooted, free-growing lucern sapped the subsoil.

In a year when abundant rains had fallen in August and the first half of September, he contrasted, on October 29, the soils of two contiguous fields which had carried barley and sugar-beets respectively. His results were as follows: —

Depth and Kind of Soil.	Amount of Water In 100 Parts of the Soil.	Amount of Water For each 100 Parts of dry Soil.	Water-holding Power of the dry Soil, for Water at 61° F.	The fresh Soil contained % of all the Water it could have held.
BARLEY-FIELD.				
In ½ ft. loamy marl	14.89	17.60	51.58	34.12
In 1½ ft. loamy, sandy marl .	18.13	22.15	58.67	73.75
In 2½ ft. sand	3.51	3.64	36.65	9.93
BEET-FIELD.				
In ½ ft. loamy marl	14.50	16.97	63.69	26.64
In 1½ ft. loamy, sandy marl .	8.82	9.86	56.11	17.25
In 2½ ft. loamy, sandy marl .	13.88	16.13	51.99	31.02

Here again the influence of the beets upon the second layer of soil is clearly marked, and it is evident enough that, under less favorable conditions, this crop might deprive the land of water so completely that the success of grain sown after it would be endangered.

At another time Wilhelm divided a field, on which sainfoin had been growing for three years, into five plots, as follows: —

No. I remained covered with the sainfoin.

Nos. II and III were spaded in April, No. III being spaded deeper than No. II.

No. IV was spaded like No. III, and was sown with buckwheat early in August.

No. V was sown with meslin (oats and vetches) in the middle of April.

Samples of earth were taken from three separate depths for comparison, viz.: —

From 0.158 metre, say	6¼ inches.
" 0.474 " "	18¾ "
" 0.790 " "	31 "

In the following table are given the quantities of water, in grm., found for each 100 grm. of dry earth at the several depths, in the various plots of soil: —

I. Sainfoin-Plot.

2 April.	5 May.	2 June.	2 July.	5 Aug.	7 Oct.
44.10	33.01	34.78	28.22	29.44	16.71
28.78	27.46	28.30	21.63	16.95	18.66
25.69	27.53	25.18	24.79	20.01	21.51

II. Bare and least mellow Plot.

2 April.	5 May.	2 June.	2 July.	5 Aug.	7 Oct.
			24.71	28.82	23.27
			22.72	20.34	19.64
			26.43	25.11	23.95

III. Bare but mellow Plot.

2 April.	5 May.	2 June.	2 July.	5 Aug.	7 Oct.
41.28	42.32	30.80			
26.59	27.45	26.84			
28.13	26.42	26.30			

IV. Buckwheat-Plot.*

5 Aug.	7 Oct.
43.13	25.91
27.82	21.20
27.40	24.15

V. Meslin-Plot.

2 July.†	5 Aug.†	7 Oct.‡
17.16	27.68	22.98
10.73	17.01	16.21
19.52	20.35	19.64

The differences between the upper and second layers in the different months depend in part upon varying rainfalls. Thus, the rainfall in the separate months from April to September was: April, 49.76 millimetres; May, 83.24; June, 59.78; July, 98.89; August, 48.52; and September, 32.66.

As compared with some of the others, the sainfoin plot No. I pumped out water from the lower layer of soil incessantly during the summer months, in accordance with the well-known habit of this plant. In localities subject to droughts, sainfoin has an advantage over most other forage crops, in that it can send long roots deep into the subsoil, there to obtain water.

The bare and comparatively firm earth of plot No. II evaporated a great deal of moisture from the surface, and from the second layer also when the times were dry. But it was on plot No. V that some of the most remarkable results of all were noticed. The meslin grew luxuriantly, and it took a great deal of moisture out from the earth; notably from the middle layer, though both the surface soil and the third layer supplied no small quantity. Such a result as this certainly goes far to prove the correct-

* No. IV was treated precisely like No. III until the buckwheat was sown.

† Just before mowing. ‡ Stubble ground.

ness of the view that winter grain is apt to fail when sown after a thirsty crop; and it supports the inference that the old prejudice in favor of bare fallows may really have depended, in many cases, upon the need of moisture, and on that account have been more worthy of respect than some modern writers have been willing to allow.

The large proportion of water found in the buckwheat-plot is noted by Wilhelm as remarkable. The experiments in this case were repeated several times, in order to make sure of the accuracy of the results. Taken in connection with the familiar fact that buckwheat succeeds well upon light soils as a stubble-crop, i. e. in the driest portion of the year, they suggested to him the thought that buckwheat may perhaps need comparatively little water. But the methodical experiments of Hellriegel count against this idea, for it was found that, ton for ton, the buckwheat-crop really transpires as much water as other kinds of plants do. It is probable in this instance that considerably less dry matter was harvested from the buckwheat-plot than from some of the other plots, for it is hardly to be supposed that buckwheat growing on a given area of land can ordinarily yield so heavy a crop as sainfoin or vetches would when grown under similar conditions.

Bare Land less dry than a Lucern-field.

There is still another experiment by Wilhelm which shows even more emphatically than the foregoing how completely water may be pumped out of the land by weeds and by weed-like crops. He divided into two parts a lucern-field, the surface soil of which was composed of loamy sand resting on a sandy subsoil with gravel below. Owing to the position of the field and to the coarseness of the gravel beneath it, it was impossible that water could be lifted by capillary action from the ground-water into the standing-room of the crop. Consequently, all the moisture in the soil came from the rain that fell upon it. On one part of this field the lucern was extirpated in the middle of April, care being taken that the soil should be loosened as little as possible, that all weeds which appeared subsequently should be destroyed, and that the land should be bare and uncultivated. The remainder of the field, which carried lucern in its natural condition, was mown four times during the summer. Samples of soil were collected at intervals from both the divisions and at different depths, and were tested for water as stated in the following table, which gives the weights of water in grams for each 100 grams of the dry earth.

Time of Collecting the Earth.	Beneath the Lucern at Depth in Feet.			Bare Land at Depth in Feet.		
	0.5	1.5	2.5	0.5	1.5	2.5
April 2 . . .	26.97	21.44	10.03	. . .	. . .	. . .
May 5 . . .	30.49	18.98	11.03	31.84	22.99	20.54
June 2 . . .	18.39	18.23	14.46	25.09	19.65	21.30
July 8 . . .	24.46	10.71	2.32	29.92	21.08	12.09
August 6 . .	24.33	10.38	2.95	27.79	18.86	16.59
October 16 . .	10.99	7.79	1.52	24.73	21.17	9.48

The amounts of rain that fell during the period of this experiment, as measured by Wilhelm, were as follows: —

Between	March	1	and	April 1,	29.18	Paris	lines.
"	April	2	"	May 4,	31.22	"	"
"	May	5	"	June 1,	27.74	"	"
"	June	2	"	July 7,	44.78	"	"
"	July	8	"	August 5,	31.54	"	"
"	August	6	"	Oct. 15,	30.09	"	"

Between May 18 and June 2 only two insignificant showers fell (0.74 and 0.22 inch.), and no copious showers fell between September 15 and October 16.

An excellent example of the power of a leafy crop to remove water from the soil is to be seen in an observation made by King, in Wisconsin, where, on May 13, land recently planted with Indian corn was found to contain in the uppermost 6 inches of soil, 23.33 lb. of water to the 100 lb. of dry soil, while in similar soil taken from a clover-field, at a point not two rods distant from the other, there was found no more than 8.59 lb. of water to the 100 lb. of dry earth. As King has remarked, the clover had evidently drunk up the water from the soil much faster than capillary action could bring it up from below, while no such drain had as yet been felt on the still bare corn land. Yet maize does, in its turn, remove much water from the land during its period of growth. King found, in fact, that at a depth of 40 inches below the surface the per cent of water in a subsoil of sand was reduced by this plant to 7 % of the dry soil, even when the water-table was only 42 inches lower than this point.

Green Crops shade the Surface Soil.

In apparent opposition to what has been said above, as to the removal of water from the soil by crops, it is often urged that green crops do good by shading the ground; that they mulch it, as it were; and there is doubtless much of truth in this idea, in so far as the surface soil is concerned. In the case of certain crops, such as carrots for example, the rows are commonly placed at such

a distance one from the other that the ground shall be completely shaded by the leaves long before the crop has come to maturity.

Indeed, evidences of moisture on the surface of the soil beneath leafy crops, such as beets and rutabagas, are so often to be seen that it is easy to lose sight of the drain upon the moisture a little lower down which such crops may occasion. The surface soil may be visibly moist, or covered perhaps with fresh moist casts of earthworms, at a time when bare land is rather dry, and a considerable effort is required in order to grasp the conception that the soil below the surface of the beet-field is less moist than would be well. As long ago as 1859, Nathusius wrote as follows: "Lupines are very apt to make land foul; and it is really wonderful to see how the poorest land — which scarcely used to grow a few annual grass-plants — is, in the shade of the luxuriant lupines, immediately covered with different weeds. Even couch-grass makes its appearance where it was formerly unknown. For such poor land the lupine has some peculiarly fertilizing influence." It is now known, of course, that these appearances are dependent upon the nitrogen-bringing power of a microscopic fungus which thrives upon the lupine roots.

Misled by the appearances above mentioned, some persons have even argued that weeds, by shading land, may prevent it from becoming dry. But this idea must be accepted with many qualifications. To refute it, it would only be necessary to examine in dry weather, at a depth of a few inches from the surface, a bare soil that had been hoed recently, and to compare the amount of moisture found there with that contained in similar soil at an equal depth near the roots of a thick growth of weeds. An astonishing difference would be perceived at once. In the words of Cobbett, "Let there be a rod of ground well set with even small weeds, and another rod kept weeded. Examine the two plots after 15 or 20 days of dry weather, and you will find the weedless ground moist and fresh, while the other is dry as dust to a foot deep. The roots of the weeds suck up every particle of moisture." Indeed, on merely pulling up a tall weed in dry weather, the earth attached to its roots will often be seen to be extremely dry.

Nevertheless, the mulching effect of a green crop is valuable on several accounts, and it is a maxim of practical experience that poor land in high, dry situations may get out of condition more

rapidly when left to itself than it would if it were kept covered with vegetation. According to Hohenstein, "When the woods are destroyed in warm and hot countries, the entire atmosphere is changed. The soil becomes hard, and its aspect arid, and the country does indeed look as if it had been worked out and exhausted for all eternity."

Crops and Mulches keep Soils cool.

Experiments by Wollny show that, during the summer, land which is shaded by growing crops, or with a covering of straw or leaves or manure, is cooler than bare land. In the following table are given the mean temperatures observed in summer weather in soils of different kinds, at a depth of 10 c.m., according as the soil was bare, or was covered with growing grass or with chopped straw.

	Loam.			Quartz Sand.		
	Grass.	Straw.	Bare.	Grass.	Straw.	Bare.
Mean daily temperature of the soil	17.0	18.0	19.1	17.9	18.7	19.5
Mean daily variations of temperature of soil .	2.3	4.7	8.3	3.8	6.2	10.8
	Calcareous Sand.			Peat.		
	Grass.	Straw.	Bare.	Grass.	Straw.	Bare
Mean daily temperature of the soil	17.2	18.2	18.7	16.8	17.9	19.3
Mean daily variations of temperature of soil .	2.8	7.0	9.2	7.4	2.6	4.3

On the average, the bare land was decidedly warmer in summer than that which was shaded in any way, and land covered with straw or manure was warmer than that on which grass was growing. It is noteworthy in these experiments that only small differences were noticed as between the different kinds of soils, because the influence of the shading material was so much greater than those due to unlike physical properties of the soils.

During the autumn and spring, the bare land was cooler than that which was covered. The daily variations of temperature were largest in the summer, and least in the autumn and spring, and these variations were much smaller on the shaded land than on that which was bare; they were less on the grass-land than on land covered with manure. Among the different kinds of bare land, quartz sand showed the largest mean yearly variation of temperature, and peat the smallest; but these differences were hardly appreciable on the plots of land covered with growing

grass. At the time when the mean daily temperature of the soil was lowest, the bare land was usually cooler than that which was covered. In general, bare land was much more sensitive to changes in the temperature of the air than shaded land. In the spring, the bare land became warm quicker than the covered land, and in the autumn it cooled off sooner.

It was noticed that the influence exerted by coverings of straw or manure on the temperature of the soil differed widely, according to the thickness of the covering. When the layer was 3 c.m. thick, the soil was cooler in summer and warmer in autumn than the grass-land; but when the layer was 1.5 c.m. thick, the soil was warmer both in summer and autumn than the grass-land; and with a layer thinner than 0.5 c.m., the soil was warmer in summer and cooler in autumn than the grass-land.

Merit of Shade.

In respect to land on which crops are growing, the point of chief importance, as regards the temperature of the soil, is the amount of shade which the crop casts. That is to say, the temperature of the soil in the summer will be so much the lower, and the variations of temperature so much the smaller, in proportion as the plants are standing more thickly, and as their stems and leaves are more strongly developed. When crops are grown in drills, the earth will be more thoroughly warmed in summer than when they are sown broadcast. So also when the spaces between the drills are wide, and when the rows run north and south, the soil will be warmer than if the spaces are narrow, and the rows run east and west. It is to be noted also that the temperature of the soil may rise very considerably after clover or grass has been mown in warm weather.

In the case of millet, which grows slowly and does not soon cover the land, it is noticed that the soil is apt to be injured by exposure to sun, wind and rain, and to become baked so hard that it seems as if it were "dead" after the millet has been harvested; and in this sense it has often been argued that a sparse growth of spindling plants is not so good for dry land as a dense covering of some leafy crop would be. It has even been noticed in some localities at the West, in cases when the spring and early summer were dry, that grain-crops may suffer less on land that has been heavily seeded than on land which was thinly sown. It is probable that the well-shaded land may be kept in a better

state of fermentation than that which is comparatively bare, and in such mechanical condition withal that air can freely gain access both to the microscopic organisms in the soil and to the roots of the crop. These remarks apply more particularly to the class of soils known as light or open, and have less significance in respect to rich loams, or to soils that are tenacious, moist, and compact.

There is manifestly a certain analogy between land shaded by a crop and that shaded by a forest. The same coolness and moisture are found at the surface of the ground in both instances, though in very different degrees, and the action of the roots upon the lower layers of soil is strikingly similar in the two cases. The shading of the land by the green crop, the hindrance which the plants give to the beating action of rain upon the soil, and the dripping of dew, as well as the exhalation of moisture from the leaves of the plants, are all good for the surface soil; and where the surface of the land is kept open, the layers next below will have better opportunity to profit from the access of air and rain than if the upper crust were baked hard.

Dew and Vapor may moisten the Surface Soil.

Having in view the enormous quantity of water which is exhaled by the leaves of plants, it is not difficult to understand how it is that, with some kinds of crops, more moisture may actually be found in the soil near the surface of the ground than in the lower layers, where the roots are in full action. Vogel found that, while the air over a fallow field contained 100 parts of moisture, the air over a field of lucern in blossom contained 125 parts, and that over a meadow of tall grass contained 150 parts. The excess of moisture in the upper layers of soil is explained by the fact, that at the surface the soil is exposed both by day and by night to the moisture which the leaves of the plants exhale, and that during the night there is an enormous deposition of dew upon the leaves, much of which trickles down to the ground and is held there. Not only is there more dew to fall in the moist air over the leafy plants than there is in the air over a bare fallow, but, since the radiation of heat from the leaf-covered land is greater than from the bare land, dew begins to fall earlier in the evening upon the leaves. According to Maquenne, the leaves of plants radiate heat almost as readily as lamp-black does, i. e. more readily than the soil or than most other substances. It is a familiar observation, for that matter, that after a clear night grass-fields are soaking wet with

dew, while adjacent bare land is dry; and this in spite of the fact noticed by Mayer, that the radiation of heat, both from leaves and from lampblacked surfaces, is diminished to the extent of two-thirds its true value when the leaves or the blackened surfaces are covered with a thin film of dew or with beads of dew.

It is noteworthy, however, that the physical forms of different plants, i. e. the manner in which their leaves join the stalks, have a marked influence upon the amount of dew which is shed from the leaves upon the soil. Thus, beets and rutabagas and Indian corn freely shed the dew which is deposited upon them. Much of it trickles down their leaves and stalks to the ground without hindrance. But potatoes, on the other hand, appear not to shed dew so easily; and it will oftener than not be noticed that the earth beneath potato vines seems to be dry.

Moreover, the mere evaporation of water from the surface soil under the leafy plants is less than the evaporation from bare land, since the shaded land is protected from the sun and kept comparatively cool. On the 5th of May, between 3 and 4 P. M., the mean daily temperature of the air of the locality being about 21° C. (= 70° F.), Wilhelm found differences of 13° and 16° C. in the air above a bare field and that above fields of lucern and sainfoin in the immediate neighborhood. That is to say, the air over the bare land was 23° F. hotter than that lying over one of the clover-fields, and 29° F. hotter than that lying over the other. Moreover, the layer of air that rests upon the soil will naturally be moister where a crop is growing than on bare land, because of exhalation from the leaves, and this circumstance will hinder evaporation from the surface soil. Indeed, it may sometimes happen, as was said, that the soil may absorb from the air a small part of this moisture. Evaporation is lessened also by the fact that the wind has less ready access to shaded land than to bare land. As has been explained already, the moistened and shaded surface-soil must be favorable for nitrification, and this fact, as well as the circumstance that certain fallow-crops can get nitrogen from the air, justifies the opinion of practical men that it is well to grow leafy and non-leafy crops in alternation with each other.

One item of evidence illustrating the presence of moisture near the surface of soils shaded by growing crops is afforded by the experience of English farmers in cleaning the land after wheat. It appears that on some soils couch-grass growing in a grain-field

is apt to be comparatively weak at the time of harvest, since it has lived with some difficulty up to this time near the surface of the soil and has not extended its root-stalks to any great depth. But as soon as the crop of grain is removed, and the couch-grass is thus permitted to grow without obstruction, it not only spreads rapidly along the surface of the ground, but penetrates deeply into the soil, so that its extirpation soon becomes a very difficult matter. If torn up immediately after the grain harvest, the root-stalks can be shaken out entire from the soil; but when the grass is left to strike deep roots, cultivation simply breaks these roots into pieces, and each fragment grows to a new plant. The popular notion that couch grass is at its feeblest in midsummer may perhaps depend in part on the fact that it is seen to suffer in some cases when left "high and dry" through the removal of a protecting crop.

Green Crops bring Fertilizers to the Surface.

One other point remains to be considered as bearing upon the practice of growing fallow-crops, instead of leaving the land bare; viz. that the capillary flow of water throughout the land from below upward will necessarily be stronger when plants are growing upon the soil than when the surface is bare. But the stronger the capillary flow, so much the larger will be the amount of soluble matters moved from the subsoil towards the surface. Hence, one merit of clover in a rotation may depend on its keeping up a constant circulation of moisture in the soil from below upward, whereby considerable quantities of ash-ingredients which the water held dissolved are brought nearer to the surface than they were before, and are left in a position where future crops can profit by them.

It is to be understood, of course, that all moisture exhaled by the leaves of plants was previously pumped into those plants out of the soil by the roots, and that a capillary movement of water in the soil towards the roots is immediately excited and maintained when the water previously in contact with the roots is thus removed. But this capillary water, as it flows towards the roots, necessarily brings thither everything which it holds in solution. The clover or other crop consumes what it needs of these transported matters, but there is always a large surplus of them over and above what can be used by the clover, and this surplus remains in the soil for the benefit of succeeding crops.

In a dry, hot climate like our own, the effects due to the transpiration of water from the leaves of plants will naturally be specially well marked. The elder Dwight, President of Yale College, long ago noticed the peculiar influence of the northwest winds of New England as bearing upon this matter. He was assured by farmers who cultivated tobacco, that the leaves of this plant are perceptibly thicker and heavier after a northwest wind has blown for two or three days than they are at any other time, and that such a season is considered the best for cutting the crop. When grass is mown under these conditions, it is noticed that the scythes become covered with the juice, which is then thick and viscid. This "gum" adheres so tenaciously to the metal that the whetstone has to be used continuously, not to give the steel an edge, but to remove the glutinous matter. Hence, conversely, the advantage of mowing grass with scythes very early in the morning when dew is upon it.

Legume Rotations.

Beside the rotations in which grass was brought in to refresh the land, other systems based upon the cultivation of legumes have for several hundred years found application in Europe. From time immemorial it has been known in a vague way that leguminous crops — such as peas, beans, lupines and vetches — do in some way act to enrich the soil. Even the Roman writers on agriculture — notably Pliny, Columella, Cato and Virgil — pointed out that it is not necessary to manure land on which these leguminous plants have just been grown, because these crops make the soil fertile. Cato said, "There are some crops which tend to nourish the earth; thus, for instance, grain-land is manured by the lupine, the bean and the vetch; while the chick-pea exercises a contrary influence; and the same is the case with barley, fenugreek and fitches, all of which have a tendency to burn up grain-land, as, in fact, do all those plants which are pulled up by the roots."

As Virgil said, grain-land is scorched by flax, oats, and poppies. In more modern times, and especially after the introduction of red clover and lucern, a multitude of European writers have told a somewhat similar story. Like Cato before him, who said that "lupines, beans, and vetches dung the land," Thaer in his day did not hesitate to call clover a plant that enriches the soil, in contradistinction to the grain-crops, which, as he said, impoverish land. Indeed, as a matter of fact, the terms "enrich-

ing" and "exhausting" plants have always found place in agricultural literature and in the familiar speech of the farm.

Gasparin, writing before the middle of this century, insisted that "The ameliorating effects of clover are incontestable. They are proclaimed by all the world, though no one seems hitherto to have tried to state them precisely. The crops of wheat which succeed clover are better and handsomer than could be got if the wheat were to receive directly, on a fallow, the manure which is applied to the clover. The following experiment affords some data: 30,000 kilos of farm-manure were applied to two hectares of rather poor land, and wheat was sown there in the autumn. Next spring, red clover-seed was strewn upon the surface of one-half the field, where it grew vigorously. In the second year, the clover was mown once and yielded 2,840 kilos of hay, but dry weather destroyed all hope of a crop of rowen. As soon as the clover began to grow again, in September, it was ploughed under, and the whole field was again sown with wheat; the half which carried no clover having lain fallow meanwhile and been well tilled. The quantities of wheat harvested were as follows: —

	Kilos of grain from the hectare which bore	
	Clover.	No Clover.
1st crop of wheat	993	1,100
2d crop of wheat	1,222	885
	2,215	1,985

It will be noticed that while the growing clover-plants of the first year lessened the yield of wheat somewhat in that year, the clover residues enriched the land to such an extent that the second crop of wheat more than made up for the deficiency of the first crop. The total yield of wheat in the two years was 230 kilos more on the clover-patch than on that half of the field which had lain fallow."

For nearly 200 years the farmers in some parts of Europe have been accustomed to count upon wheat's succeeding as well, or even better, after a heavy crop of plastered clover as if the land had been dunged for the wheat; and although the facts of observation were most mysterious and unaccountable until Hellriegel discovered how it is that the legumes can get nitrogen from the air, the facts had nevertheless come to be very generally accepted by practical men, and had been laid down as the bases of rules in agri-

cultural practice. It is known, indeed, that in some districts of England, beans were introduced into the three-course system at a very early period, even as early as the time of common fields; and it is true that Markham, writing in 1625 of barren clays that had been improved by applying [calcareous?] sea-sand, directs that the land should be sown with wheat or rye for the first two years, then folded with sheep and sown with barley, after which oats can be grown during three consecutive years. On the seventh year, peas or beans may be sown, after which, if the land be laid down to grass, it will yield excellent crops.

Infield and Outfield.

In some parts of England it became customary very early to have the arable land of a farm in two great divisions, known as "infield" and "outfield" respectively.[1] The infield was usually smaller than the outfield, and was near the farmyard; it comprised a third or a quarter of all the cultivated land. The size of this division was determined by the amount of dung produced in the farmyard, and it received the whole of it, usually upon the crops of a three-course rotation, viz.: 1, wheat or barley; 2, oats or barley; and 3, beans or peas. But on the outfield the rotation was very different. Sometimes it was grain for two years, followed by two years of fallow field used as pasture; and sometimes there were three fields, each of which was kept three years in grain, and then given over to six years of the poor, fallow, unseeded pasture.

It is evident that under these conditions grass rotations and legume rotations overlapped one another. But it was the recognition of the truth that the leguminous plants, such as peas, beans, vetches, and clover, — as well as hoed crops, such as roots or potatoes, — can be grown with success on land which is not in fit condition to bring a good crop of grain, that gave rise to intelligent systems of rotation such as have long prevailed in many parts of Europe.

Here was a decided step in advance, — an improvement based on intrinsic merit, and thereby differing essentially from the original three-course system, which depended in good part merely upon physical and social circumstances. Indeed, looking solely

[1] A similar custom prevailed in Germany also. But it is to be noticed that, even before any land had been enclosed and occupied as separate farms, the terms inner and outer fields were used sometimes to distinguish between the tilled land adjacent to the village and the outlying land that was devoted to pasturage.

from the chemical point of view, the original three-course system could hardly be regarded as a true rotation, were it not that in the practice of making barley or oats follow wheat, instead of growing wheat twice in succession, there is a clear recognition of the fundamental idea that different crops act differently upon the soil; and that this idea is the germ of all the improvements which have since been made.

The introduction of beans in the third year, as a preparatory crop for wheat, was undoubtedly a decided improvement upon many stiff soils; and there are several other very old Belgian and English systems which are remarkable for the clearness with which they illustrate the idea that no two crops of like needs should ever succeed one another. Thus, in the county of Kent, there was a two-course system of, 1, grain-crops, and 2, part legumes and part turnips, for sheep-food; or of, 1, grain, and 2, beans. The sheep-fold was the source of manure for the wheat. The sheep were fed during spring and summer upon vetches, and during winter upon turnips. Arthur Young mentions an analogous rotation of turnips and barley alternately, with the occasional intervention of clover, on very poor light land in Durham. The turnips were fed off, as in the other case, to folded sheep. Here again are just conceptions of the real significance of rotation. Most of the modern systems are mere extensions of these ideas.

As has been pointed out by Caird, the field experiments of Lawes and Gilbert on growing wheat continuously may be cited in illustration of the significance of green crops in rotations. It is not surprising that the soil of their field should exhibit signs of exhaustion after forty successive crops of wheat have been taken from it. But, as is well known, this trouble could be avoided by introducing red clover between the grain-crops at appropriate intervals, and practically it is done away with by interposing occasionally heavily dunged green crops. Experience has taught, in England, that one good method of obtaining profit from grain is to manure the land heavily for mangolds, and to follow the beets with crops of wheat, barley, or oats for several successive years. Clover also is introduced occasionally, and grain-crops are grown after it, care being taken to keep the land free from weeds, and to manure all the grain-crops with nitrate of soda and with superphosphate. When the land shows need of a change, the rotation begins again with a heavily dunged green crop; after which there

is no need for some years of giving the grain-crops any other manure than nitrate of soda and superphosphate.

Minor Rules of Rotation.

Several writers have endeavored to systematize the lesser rules of rotation somewhat as follows: —

Such plants as tend particularly to exhaust the soil, like the grain-crops, should only be sown when the land is in good heart. They should not be made to succeed one another, but may well be followed by plants that are less exhausting.

In proportion as a soil is found to be easily exhausted by cropping, plants that are non-exhaustive should be grown more frequently upon it.

On heavily manured fields, such plants should be sown as can bear the rankness of fresh manure; while other plants may follow them to good advantage.

It is advantageous to alternate plants that have tap-roots with those which have spreading roots.

Some crops, like wheat, demand a firm footing, i. e. they grow best on soils which are tolerably compact; while other crops, such as turnips, for example, prefer a looser tilth.

No two crops favorable to the growth of weeds should be permitted to succeed each other.

As with weeds, so with insects and fungi. It is essential in many cases to change the crops frequently, to hinder the increase of these pests. There are various insects injurious to grain which would increase to an alarming extent if the land were devoted exclusively to grain-crops year after year. But when a crop intervenes on which the insects cannot live, as beans or turnips after wheat or oats, then the whole tribe of grain insects may perish or disappear from the field for want of proper food. The finger-and-toe disease, and the clump-foot, in like manner prevent the continual cultivation of turnips and cabbages. Farmers and market gardeners in the vicinity of Boston would be glad to grow cabbages year after year upon the same land, but they cannot because of the disease called clump-foot. So it is with beet-roots in Europe. In some localities, nematode worms and other pests prevent the continuous cultivation of the sugar-beet. It is because of this inconvenience, as well as for the sake of obtaining beet-juice comparatively free from saline matters, that some German authorities think that sugar-beets should not be grown on any given field oftener than once in six or eight years.

"*Fallow-crops.*"

For a very long time now, green crops, such as those just mentioned, have been called "fallow-crops," and have been substituted almost everywhere for the old bare fallows. At one time and another, the agriculture of Europe has been greatly modified by the introduction of horse-beans — to be grown on strong, moist, clayey soils — of turnips and mangolds, and (after the discovery of America) of the potato and of Indian corn at the South of Europe, and the sugar-beet, because these crops can be interpolated between crops of the cereal grains, to the great improvement of the condition and the productiveness of the land, while the wasteful fallow fields may be done away with. A comparatively recent instance of such substitution occurred in Scotland towards the middle of this century, when bare fallows were abandoned in favor of crops of turnips, — grown with the aid of dung and phosphatic fertilizers, — with the result that the product of meat and grain upon a multitude of farms was largely increased.

Most fallow crops are cleansing crops, since the hoeings and cultivation to which they are subjected tend to kill those kinds of weeds which prosper in fields of grain or of grass. Beside their power of utilizing fresh manure, several of the fallow-crops tend to enrich the soil, or, rather, they work against the exhaustion of the soil in several ways, for some of them serve to collect nitrogen from the air by means of micro-organisms on their roots, and not a few of them create a great movement of moisture, by which ash-ingredients are brought from afar into the standing-ground of the plants, much in the same way that a forest brings food to the surface. And just as a forest enriches the soil with its leaves, so several of the fallow-crops, particularly some of the leguminous plants, leave a large quantity of vegetable matter in the soil. In order to illustrate this point, Boussingault had the roots and stubble of several crops forked out from measured plots, and he determined the weight in kilograms of refuse matters left in and upon a hectare of land by each of the crops mentioned in the table: —

	Crop Harvested on a Hectare.		Roots, Stubble, Leaves, Vines and other Refuse, excluding Straw.		In the Refuse.	
	Fresh or Air-dried.	Dried at 110° C.	Air-dried.	Dried at 110° C.	Nitrogen. Kilos.	Ashes. Kilos.
Clover-hay .	2,500	1,975	2,000	1,547	27.9	194.9
Potatoes . .	12,400	2,988	2,870	687	15.8	122.3
Mangolds .	14,921	1,820	10,472	1,167	52.5	250.9

Oats . . .	2,031	1,608	912	650	2.6	33.1
Wheat . .	1,172	1,002	700	518	2.1	36.3

On adding together the figures given above for the five crops plus those for a second crop of wheat which belonged to the rotation, we obtain the following sums total: —

Sums of crops	34,196	10,395	17,654	5,087	103.0	673.8
Manure applied	49,086	. . . .	. . . .	10,161	203.2	3,271.9

Whence it appears that the residues left by the crops and buried in the land during the rotation amount to almost half the weight of the manure which was applied at the beginning of the course. The contrast is obscured, however, by the fact that either the beet-leaves or the potato-vines should be left out from the additions, since only one or the other of these two crops would be grown in the five-years course which Boussingault studied. The two crops were alternative.

With regard to clover, it appears that for every ton of hay harvested 1,600 lb. of roots and stubble are left upon the land, all the weighings being regarded as air-dried products for the sake of comparison. It is no wonder, then, that grain-crops succeed well after clover, for they must find abundant nourishment in such a mass of decaying organic matter. Unlike the stubble of a ripe grain-crop, from which almost everything has passed up towards the seeds before the crop was harvested, the clover-refuse is necessarily rich in nitrogen because of the nodules on the roots, and in case the plant is mown while yet green, and before it has reached maturity, the roots will be well stored with ash-ingredients also. In experiments made by Heiden, it appeared that, of the total nitrogen produced by a clover-crop (roots included), 58 % were contained in the stalks and leaves above ground, and 42 % in the roots. In proof of the fertilizing power of clover-refuse, Boussingault cites the fact that wheat taken before clover, in the rotation studied by him, habitually gave 16 or 17 hectolitres of grain to the hectare, while wheat taken after clover gave 20 to 21 hectolitres.

Clover accumulates Nitrogen.

Many English farmers had noticed, when a clover-crop is mown twice, and the hay or grass is all removed from the field, that the land is left in better condition for wheat than if the clover had been mown once for hay, and the sod had afterwards been pastured by sheep, — a result which is somewhat surprising in view

of the well-known fertilizing power of the excrements of sheep. Indeed, some farmers had satisfied themselves that even when the second crop of clover is left to ripen, and the clover-seed is harvested, the succeeding crop of wheat will be better than if the clover had been mown twice for hay, or mown once, and afterwards fed off by sheep. By putting these opinions to the test of experiment, Voelcker has shown that they are well founded. In spite of the fact that a good crop of clover removes from the soil more phosphoric acid, potash, lime, etc., than almost any other crop, and fully three times as much nitrogen as an average crop of wheat with its straw, there does nevertheless accumulate in the surface soil of a clover-field a large amount of nitrogenous matter. Part of this nitrogen was contained in leaves which were dropped during the growth of the clover, but most of it in roots. Voelcker observed that the roots of clover-plants which were allowed to go to seed were actually stronger and more numerous than those of plants which were mown twice for hay. Not only were a greater number of large roots formed by the seed-clover, but more than twice the weight of roots was got from this plot in November than had been obtained in September from the plot which was mown twice. Perhaps the roots may have seemed to be particularly large and heavy because of an abundance of nodules upon them? Each of the different layers of soil examined was richer in nitrogen after the seed-clover than after the two crops of clover hay. Very nearly the same percentage proportion of nitrogen was found in the roots from the two plots, whence it follows that much more nitrogen must have been left in the land by the abundant roots of the seed-clover than by the roots of the hay-crops. More leaves fall upon the ground also when clover is grown for seed than when it is mown for hay. So, too, when sheep are pastured upon clover-sod, it is to be presumed that the development of roots, and of nodules on the roots, may be checked, and that less nitrogen will be left in the land than if the plants had been allowed to grow larger, as is the case when they are mown for hay. Some of the results obtained by Voelcker are given in the following table.

Residues left in the soil by a crop of	Clover mown twice. (Total yield, 4 long tons to the acre.)	Clover mown once, then left for Seed. (Yield, 2.5 tons hay and 3 cwt. seed.)
Pounds of dry roots to the acre . . .	1,493.5	3,622.0
Pounds of nitrogen in these roots . .	24.5	51.5

Pounds of nitrogen in upper six inches of soil of an acre	3,350.0	4,725.0
Pounds of nitrogen in 2d six inches .	1,875.0	3,350.0
Pounds of nitrogen in 3d six inches .	1,325.0	2,225.0
Pounds of nitrogen in upper twelve inches of soil, and in the roots . .	5,249.5	8,126.5

Voelcker calls attention to the fact that the nitrogen left by a clover-crop is not only large in amount, but is very evenly distributed through the whole of the cultivated soil, in such wise that it can benefit each and every plant of the succeeding crop. He suggested also that the nitrogenous matters are doubtless readily transformed to nitrates, as has since been proved to be the case. It will be noticed that there were 2.5 tons of nitrogen to the acre in the uppermost foot of the soil where the clover was twice mown, and almost as much in the uppermost six inches of the soil on which clover had gone to seed. In the foot of soil where clover had seeded, there were found four tons of nitrogen.

It is to be remarked that these experiments and observations of Voelcker were made long before the doctrine of symbiosis — which they so strongly confirm — had been thought of by agricultural investigators, and that they are all the more valuable on that account. Indeed, the fact, as here set forth, may be accepted as a typical illustration of a whole class of phenomena only too familiar to farmers; as when, for example, one or another crop is seen to "kill the land" or to "improve" it. The fickleness of the onion-crop on new or untried land is one familiar example, while the merit of clover as a forerunner of grain is notorious.

Quantity of Roots, etc., left by Crops.

Several observers have made detailed observations as to the amounts of stubble left by various crops.[1] Gasparin, in Southern France, observed that a field of lucern — which had lasted 5 years and produced nearly 16 tons of forage that contained 2.5 %, or 800 lb., of nitrogen — produced over 16 tons of dried roots and stubble that contained 0.7 %, or 229 lb., of nitrogen. The following table by Weiske gives the weight in German pounds (= 1.1 lb. avoirdupois) of residues and fertilizing ingredients left on a Morgen of land (= 0.631 acre), on the average, by the crops enumerated.

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[1] See Heiden's Düngerlehre, I. 72, and III. 243; also Hellriegel's "Beiträge," p. 166 *et seq.*

There are left in the Ground Pounds of	Rye.	Barley.	Oats.	Wheat.	Red Clover.	Lucern.	Sainfoin.
Stubble and roots	3,019	1,142	2,167	1,994	5,116	5,554	3,401
Organic matter .	2,074	924	1,339	1,369	4,015	4,856	2,814
Ash-ingredients .	945	218	828	625	1,101	688	587
Nitrogen . . .	37.6	13.2	15.4	13.6	110	78.2	70.8
Potash	18	6	14	11	47	21	25
Phosphoric acid .	15	7	17	7	43	23	17
Lime	42	24	49	44	150	113	67
Magnesia . . .	8	3	7	6	28	14	18

There are left in the Ground Pounds of	Crimson Clover.	Serradella.	Buckwheat.	Peas.	Lupines.	Rape.
Stubble and roots . .	2,870	1,795	1,259	1,848	2,027	2,557
Organic matter . . .	2,311	1,482	992	1,463	1,711	2,200
Ash-ingredients . .	559	313	267	385	316	357
Nitrogen	58.7	37.2	27.5	32.5	35.8	34.9
Potash	15	5	5	7	10	27
Phosphoric acid . .	14	11	6	9	8	18
Lime	78	46	46	41	46	71
Magnesia	10	8	4	6	7	8

The following table gives the results obtained by King, in Wisconsin, in experiments made in special cylinders of earth.

There was produced by a crop of	Lb. of dry matter per acre. In tops.	In roots.	Ratio of top to root. Tops. Roots.
Indian corn . . .	19,845	2,901	6.84 to 1
Oats	8,189	3,658	2.23 to 1
Barley	14,196	4,208	3.34 to 1
Red clover . . .	12,486	3,121	4. to 1

In Germany, the white lupine as well as the clover-crop has been found to be an excellent preparatory crop to precede winter wheat, and the following experiment of Dietrich fully supports this view. He found, in round numbers, 2,000 German lb. of roots and stubble to a Hessian acre (= 0.59 English acre), and in this mass of refuse there was contained some 33 lb. of nitrogen, 922 lb. of carbon (= 3,382 lb. carbonic acid), 41 lb. of lime, 1¼ lb. of magnesia, 5 lb. of potash, and 7 lb. of phosphoric acid. Experiments by Schultz go to show, however, that, in order that the lupine (yellow) may serve as a satisfactory preparatory crop for grain, the conditions must be such that a good state of fermentation of the land shall be insured. He found that, while on warm loamy sands lupines were an excellent preparatory crop, they served no such purpose on certain loamy sands that were cold and dry. On such land grain did not succeed after

lupines, even in cases where the lupines themselves had grown freely. No matter whether the lupines were ploughed under or carried off from such land, grain did not do well after them; not even when the land was fertilized with half a dressing of farmyard-manure. But on marling the land, and fertilizing it with a mixture of kainit and a plain superphosphate, the lupine immediately became an excellent preparatory crop for rye and oats, even upon the poorest of the fields. The inference is that the soil had now become capable of supporting ferment organisms which are favorable for the growth of vegetation. It was observed, furthermore, of the poor land, when lupines were grown upon it in alternation with sheep pasture, that after 5 or 6 crops the lupines failed. The land became "lupine sick." But the trouble was cured immediately by a dressing of 520 lb. kainit to the acre. Beside its power of getting nitrogen from the air, it is to be noticed that the lupine is a plant that succeeds best in deep soils, and that from the structure of its roots it is well fitted to take food from the subsoil. Hence it would seem to be especially proper to regard the residues left upon the land by it as contributions from the subsoil to the surface.

Clover as a Preparation for Wheat.

The rotation of clover with wheat is practised in some parts of this country; in Ohio, for example, and in some of the grain regions of New York. In case the clover "catches" well, there is obtained a valuable crop of hay, while the land is kept free from weeds. In some places the custom is to sow clover-seed with oats or wheat and to plough under the clover with the stubble, after the grain-crop has been harvested, as a preparation for winter wheat. Practically the sole cost of the fertilization in this case is the price of the clover-seed. Sometimes, instead of growing wheat, Indian corn is planted the next spring upon land thus prepared.

It will be noticed that in any event clover-stubble yields what is to all intents and purposes a green manuring. The case is widely different from that of a crop of flax, for instance, for the flax-plant is wellnigh completely removed from the land. There is no question withal that the nitrogenous residues left in the soil by clover gradually change to nitrates. This fact is illustrated by an experiment of Lawes and Gilbert, who tested for nitrates, at the end of March, in soils which in the previous year had borne re-

spectively wheat- and clover-crops. The clover had been ploughed under in October, while the wheat-stubble was untouched. There was found in the wheat-land 14.5 lb. of nitrate-nitrogen to the acre in the uppermost 27 inches of soil, while the clover-land contained 38.9 lb.

And yet it is true that it is not merely the quantity of refuse left by clover, nor the amount of nitrogen in this refuse, which can explain the superior merit of this crop as a forerunner of wheat. It is to be inferred that the quality of the nitrogen in the nodules on clover-roots is specially well fitted for supplying food to the wheat-plant. As may be seen in one of the foregoing tables, the crop of beets examined by Boussingault left much more refuse on the land, and much more nitrogen and ashes in this refuse, than the clover did; yet beets are not so much esteemed as is clover as a crop to precede wheat. It is noteworthy that in this particular rotation wheat did not succeed well after beets; not so well, in fact, as it did after potatoes even, which leave a much smaller amount of refuse on the land than beets.

In explanation of these differences, Boussingault called attention to the fact that beets act directly and somewhat emphatically to exhaust the land, while clover does not. Hence, while the quantity of plant-food returned to the soil in the beet-leaves might hardly be sufficient to compensate for that carried off by the crop of beet-roots, the clover-crop has really taken very little (nitrogen) from the land, though it has taken much from the air, so that the good effect of the clover may depend both on matters in the soil which it has refrained from taking and on those left upon the land in its roots and stubble. The same reasoning will apply to potatoes, which, though much less exhaustive than beets, do not act to fertilize the soil as clover does. Another point to be borne in mind is the fact that after clover wheat may be sown at any time which may seem to be proper or desirable, while by waiting until beets have been harvested the season might be too late for the most advantageous sowing of winter wheat. Still, according to Bréal, the yield of crops sown upon land where a mere grass-sod has been ploughed under is by no means proportional to the mass of organic nitrogen which has accumulated in the soil during the life of the grass. This nitrogen is not of so good quality as that in clover-roots, and it does not nitrify so easily.

Although it is true that beets are always regarded as a fallow-crop, and are said on the Continent of Europe to succeed well after winter wheat, and to serve well in many localities as a forerunner of spring wheat, it has often been insisted that, upon soils which are firm enough naturally, and on those which have been properly compressed, winter wheat succeeds out of all proportion better after clover than it does after beets or potatoes, or even after a bare fallow. As Walz has stated, this last observation was made thousands of times at the period when the old three-course plan was gradually being changed to systems of rotation in which clover found its place. At one time Lawes and Gilbert grew wheat on one plot of land which had previously borne clover, and at the same time they grew wheat after wheat upon another plot in an adjoining field,—no manure having been applied to the land in either case. From the plot where clover had grown without help from manure, they harvested 29.5 bushels of wheat, or 14 bushels more than were got from the plot where wheat was grown after wheat without manure. This result, as they say, is quite consistent with those obtained in ordinary farm practice, though at the time this observation was made it was not a little surprising that so large an increase as 14 bushels to the acre should be obtained, in view of the fact that the unmanured clover which preceded the wheat had taken from the land very much larger quantities both of ash-ingredients and of nitrogen than were removed by the unmanured wheat-crop in the same year from the adjoining field.

The Peculiar Merit of Clover.

The apparent anomaly admits of ready explanation now that it is known that clover is habitually supplied with nitrogen from the air through the action of microscopic organisms which live upon the clover-roots. It is to be remembered, also, that beets and other root-crops exhaust the upper layers of the soil of available nitrogen much more completely than either beans or clover do. Indeed, from the very fact that they are supplied with nitrogen from the air, beans and clover are remarkably non-exhaustive in this particular respect. So too, as Dehérain has insisted, beets —like tobacco, and in some degree sorghum and fodder corn—are apt to take up uselessly great quantities of nitrates which might be carried off the land, if the leaves were to be used as fodder, and so be stolen from the land and from the succeeding crop.

The supreme merit of clover as a preparatory crop is made conspicuous by contrasting it with a crop of mere grass. Thus, in England, where ray-grass is often grown as a substitute for, or successor of, clover, it has often been urged that, as a forerunner of wheat, the grass by itself cannot be compared with clover. Far from enriching the soil, as clover does, ray-grass is an exhausting crop, and is unfitted on this account to precede wheat. Arthur Young has cited an experiment made in Kent, where twice as much wheat was harvested from that half of a field which had been in clover, previous to the sowing of the wheat, as was got from the other half of the field, which had been in ray-grass.

Another old English observation, cited by Marshall, was that on heavy land barley often does poorly after turnips, though on light land barley commonly succeeds well after turnips. Perhaps because of changes in the tilth of the soil, brought about by the trampling of cattle or sheep which have eaten the turnips on the land? In some heavy land districts in England, where it is customary to grow wheat after clover, beans, and peas, there was thought to be a special risk that the wheat might not do well after the peas. It was deemed best to sow the wheat later both after peas and beans, and to use rather less seed, than after clover. In some places, pains were taken to draw and remove the bean-haulm, for if bean-stubble were to be ploughed under it would be apt to "keep the soil too hollow." Moreover, it was thought to afford a refuge for snails, which sometimes did much harm to the wheat.

Wheat grows best on Firm Land.

Stress has often been laid on the different mechanical effects produced in the soil by the different kinds of fallow-crops, for wheat is apt to fail on soils that are too mellow, as well as on those which lack consistence and solidity. Gasparin has called attention to the fact that wheat is apt to come up thin and light when sown on land that has been trenched so deeply as it has to be trenched in order to extract the roots of madder, when this crop has been taken from the land, simply because the act of trenching has left the land so loose and open that the young wheat-plants find no adequate support. In such cases as this it is often very noticeable that the wheat grows well enough on those parts of the field where horses and wagons have passed over the land and made it firm and hard.

It was on this account that some English farmers early in this century, while regarding clover and horse-beans as excellent forerunners of wheat, did not consider potatoes so well fitted for the purpose. For although potatoes, like clover or beans, may be dressed freely with manure, and forced as hard as may be wished, it was thought that the loosening of the soil incident to the cultivation and harvesting of the crop rendered the land less fit for wheat than it was in the other cases. Hence, they preferred to sow barley and clover after potatoes, and to have the wheat-crop succeed the clover, though much will depend, of course, on the time when the tubers are harvested, for, as Arthur Young intimated, early potatoes are a much better preparatory crop for wheat than are potatoes which ripen late.

It is probably because of the fact that early ripening potatoes are grown nowadays that potatoes have come to be esteemed in many localities in this country as a crop to precede winter wheat. Thus, Terry, in Northern Ohio, has said: "A clover-sod may be turned under directly for wheat, but it is not as well as to grow a crop of corn or potatoes first and then put in the wheat. There is most too much nitrogen in the clover, if the growth was heavy, for wheat to follow. The growth of straw is too great, and the wheat lodges and the yield of grain is not up to expectations. Our best farmers are generally agreed on this point. I find almost too much nitrogen after growing a crop of potatoes first, where the second growth of clover is turned under. It is the same where manure is applied directly to the crop here. My next neighbor has a piece badly down. He put the manure on the clover in the spring for potatoes, and then drilled in wheat in the autumn. The manure got rotten just about in time for the wheat, and has given it too much nitrogen. The worst piece of lodged wheat I ever had came from manuring potato-ground in the spring in this same way, and a dry season following the potatoes used little of the manure. I prefer to use the manure to grow the clover. It is safer. . . . I do not believe there is any better preparation for wheat (here in Ohio) than a thoroughly worked potato-field which had been a heavy clover-sod the year before." [All of which is of special interest as illustrating the rapidity of nitrification in this country during the hot summer weather.]

Summer Grain after Root-crops.

None the less, it is a rule of practice in many parts of Europe,

that not winter but summer grain should be grown after roots, and especially after potatoes. It is held to be good practice in these localities to grow the clover, which is to precede wheat, on perfectly clean, well manured, and well worked land; and to this end the clover-seed is sown with barley on land from which beets or potatoes or cabbages were taken during the previous year. It is to be remembered, however, that one reason why roots and potatoes are not specially well fitted to precede winter wheat on heavy land abroad is that there is a very considerable risk of puddling such land by ploughing it in rainy autumn weather as a preparation for putting in the wheat. In Northern Europe there is not ordinarily time enough between the harvesting of the roots and the sowing of the grain to permit the farmer to pick and choose a propitious moment for making the seed-bed.

On the Cotswold Hills, Marshall found, in 1788, that all the farmyard-manure was applied to the turnip-crop, and that the rule was to grow barley after the turnips. Wheat, on the contrary, was grown after ray-grass, which had followed the barley and had been kept down during two seasons. The grass-sod was ploughed under early in July, and the wheat was sown in August or September. Between the sowing and coming up of the wheat, sheep were penned upon the land, or driven over it repeatedly, to compress it. The soil of this district is a calcareous loam, somewhat admixed with gravel. Generally the loam "is of a binding, tenacious quality, baking with drought, and clinging to the feet in wet weather. It may be called turnip and barley land."

One thing to be considered is the risk that, after some kinds of crops, weeds may so thrive as to choke the slow growing young wheat-plants in the spring. In this point of view, the wheat-crop had better follow a bare fallow, or such forage crops as are mown when young, or hoed crops which are kept clean by frequent tillage, or crops which are removed from the land early enough to give time to check the growth of weeds. Beside clover and beans, rape, meslin, flax, root-crops, and early potatoes fulfil this condition. Indeed, in some parts of England, upon rich, deep, dry loams, potatoes and wheat were formerly grown alternately for many years in succession. The potatoes were heavily manured, and were dug in September or October, the wheat being sown at the end of October or early in November, at the rate of no more that 4 pecks to the acre (probably in drills, so that the crop could

be weeded). Under this treatment there were obtained from 300 to 500 bushels of potatoes to the acre, and from 30 to 40 bushels of wheat.

Wheat differs from Rye.

It is none the less true, however, that in England practical men have always insisted that land which is to bear wheat cannot be too old or solid, provided that it is fertile and free from weeds, and that there is enough loose loam at the surface to cover the seed. They hold that "a firm standing" is required for the healthy development and proper ripening of wheat; a view which consists with the notion, very prevalent in England, that "the finest and heaviest wheat grows in land with a bottom of clay." (Cobbett.)

In pot experiments made by Gasparin, wheat was sown in soils sifted to several conditions of fineness, some samples of which were not compressed at all, while others were subjected to various degrees of pressure. No water was poured upon the surface of the soil, but it was supplied at the bottoms of the pots, whence it was sucked up into the earth by capillary attraction. It was found that the wheat-plants grew best in fine earth which had been moderately compressed, while in coarser and less compact soils the crop suffered.

Gravel and sand is for rye, and not wheat, says Tusser, speaking of course of England, and the conviction is wide-spread, not only that rye may readily be grown on sandy loams where wheat would fail, but that, unlike wheat, rye actually prefers a loose soil. It is often urged that, in case any one is compelled to grow rye on clay, special care should be taken to plough and to harrow the land repeatedly, in order to make it as light and friable as possible; and yet it is a tenet of practice that the land on which rye is to be grown should be well "settled." The argument is that rye-land may be light and mellow indeed, but that it should be firm also in one sense. Instead of sowing rye on newly ploughed land, it is held to be well to wait three or four weeks, when possible, before putting in the seed, and this in spite of the fact that, as a general rule, winter rye should be sown early. But some writers have urged that this delay is advantageous, not so much because the soil settles, as that time is needed for the constituents of the manure to soak into all parts of the soil before the seed is sown.

Oats do well after Grass.

It would appear that, as a general rule, wheat is seldom grown in England upon inverted old grass-sods, excepting on soils which are particularly strong. Almost everywhere oats are preferred to wheat for sowing on freshly broken grass-land in regions where the soil is light, and the remark is true of many localities where wheat can be grown with success after the vegetable matter of the sod has once been reduced by decay and tillage. More than 100 years ago Marshall noticed in the Midland Counties of England a long-established rotation which consisted of grass, kept down 6 or 7 years, then oats, and thereafter wheat, followed by barley and clover and grass-seeds. In the West of England at that time the custom was to sow wheat on old pasture-land, the sods of which had either been pared and burnt, or left to rot during a fallow year. For manure, lime was used, with perhaps a small portion of dung.

It is said also that the hollowness due to the presence of sods and the undecomposed grass and roots render the wheat-plant more liable to be killed by frost, and more susceptible to the attacks of insects, than is the case when the sods have been rotted or impacted. Hence, the general rule in England, on light land, is to grow turnips or the like after grass, and to have sheep eat off this fallow-crop in order that the soil may be consolidated by the trampling of the animals. It has been reported that very striking changes were brought about in some parts of England by the introduction of this system of husbandry, in that enormous quantities of wheat were grown with success on light soils where the cultivation of this crop had previously been thought to be impossible. Quite recently the same result has been noticed in a Scotch locality (Bute), viz. that "Those farmers who have bestowed more attention on the turnip-crop than to the growing of early potatoes are better off than their neighbors, and their farms are in much better condition. [Folded] Turnips leave the soil in much better condition for the growth of the next crop, and one can easily distinguish by the appearance of the white crop whether it has been sown on potato or on turnip ground." Of course, the foregoing remark can apply only to suitable soils, that are sufficiently light and dry, for on strong, retentive land, in a moist climate, serious difficulties would be encountered on attempting to feed off turnips from the land by means of sheep.

In case of need, sheep are sometimes folded on the wheat early in the spring, as a means of saving the crop. So too in this country, on the prairies of the Northwest, in regions which are popularly supposed to be wholly given over to the production of spring wheat, it is said that this crop is seldom or never grown upon the newly broken original sod-land. Either Indian corn, or potatoes, oats, or beans, are taken as the first crop upon the sod-land, though afterwards spring wheat is grown incessantly year after year. Mr. Russell has said of the Canadian shore of Lake Ontario: "The soil, I could see at a glance, was not suited for growing autumn wheat in this climate. It was too soft and black in the color, wanting that peculiar hardness of quality which is essential here for wheat. Spring wheat, oats, barley, and potatoes are the chief crops. To

grow autumn wheat well the land must be pastured for 3 or 4 years to give it the necessary firmness, and then fallowed out and out nearly a whole year before the wheat is sown." In Michigan he noticed, of fields seeded down to grass and clover, that the grass was allowed to remain 2 or 3 years to solidify the soil, and render it better adapted for winter wheat. He says further, of Illinois: "I saw few fields of autumn wheat on the prairies, and those were mere patches. . . . It is owing to the nature of the soil of the prairies, and not to the climate, that so little wheat is sown in autumn. This appeared quite evident from the fact of autumn wheat being sown on all the gravelly soils of the prairie knolls. The high winds, attended with intense frosts in winter, often destroy the wheat-plants, and the spring frosts and thaws also are apt to throw them out of the loose and open prairie soils. These agents, and the tendency of the wheat to mildew, are the causes of so little being sown in autumn."

Wire-worms may injure Wheat.

In some parts of England farmers have objected to changing their four-course rotation to one of five years, by allowing the clover (and ray-grass) to grow during two years instead of one, because they have observed that "wheat seldom succeeds so well after a second as after a first year's seeds." [Perhaps because the more abundant clover-roots of the first year leave more useful nitrogen in the land?] So too in that country, formerly, when old pastures were to be broken up, wheat was rarely grown as the first crop, no matter how high its price, excepting cases where special pains were taken to leave a firm bed for the wheat by paring off the sward as thin as possible, then burning it, and subjecting the land to very shallow tillage. In the words of Mr. Pusey, "It is well known that nothing is more difficult than to secure the first wheat-crop on newly broken grass-land, and many farmers will not attempt to grow a wheat-crop at starting. The wire-worm, moving about easily in the soil loose with the remaining roots of the grass, often destroys a large part of the plants of wheat, . . . and the state of the soil itself, thus interwoven with a network of fibres, allows the rising wheat to shake itself loose at the root, and so to perish for want of support." In the words of another English writer, "All new arable land has a tendency to become hollow and spongy; and if the ground is loose, wire-worms, where they abound, can more readily carry on their destructive operations. . . . On peaty soils in particular, just broken up from pasture, even oat-crops are sometimes destroyed by the ravages of the wire-worm. Instances are upon record in England where — instead of paring and burning — the grass-land has been trenched, so that both the sod and the loose upper mould should be buried. In one case where this was done, four heavy crops of wheat in succession were grown on newly broken grass-land. Upon clover-sod, however, or better yet upon sainfoin, it has long been customary in many parts of England to sow wheat upon a great variety of soils, and the practice is esteemed to be one of the very best methods of growing wheat.

Banister, writing, in 1799, of the county of Kent in Southeastern

England, urged that, "on every light soil, except wet gravels, wheat is found to prosper much better after a clover-lay or pea-field than when sown on a fallow." He explained, that on chalks and other light soils many different kinds of fields may be devoted to wheat, such as clover-lays, pea-fields, oat-fields, fallows, turnips, etc., but that, of all these, clover-lays are accounted the most kindly, so much so that on thin land it is customary when the clover has continued a year to break it up and sow wheat, with one ploughing. The clover is rarely suffered to continue longer on the ground than one year. Pea-fields, when the ground is in good heart, are by no means improper for sowing with wheat on the kinds of soils now under consideration; and after turnips, also, it is no unusual circumstance to grow a full crop of this grain. But neither fallows, nor oat- nor barley-fields, on light land, are suitable for growing wheat, and barley-fields are worse than the others. On light soils a contrary practice must be pursued from that which is necessary on clays; that is to say, the land must be brought to a close and firm texture before seedtime, and this can never be done so effectively as by sowing on a clover-lay, which, having been broken up towards midsummer, will, by the aid of succeeding rains, have acquired a sufficient degree of firmness before the middle of October, and then it is that such land is in proper order for the reception of wheat. But the sowing of wheat after barley on light soils is always hazardous, because the barley-fields are apt to work to a finer tilth than is suitable for wheat, and it is not a mark of good husbandry to sow wheat after barley. In case wheat has to be sown after barley, it would seem to be well to plough the stubble but once. On light soils, nothing is more injurious to wheat than to sow it in a light and hollow furrow. There is little doubt that, in case this were done, the crop would be totally destroyed in the spring by the worm which on thin lands frequently occasions irreparable havoc in spite of every precaution. Even when clover has been suffered to remain on land longer than one year, it is a very hazardous experiment to sow the ground with wheat or oats when the clover is broken up, since from the length of time during which the surface of the soil has been covered with turf the worm which destroys grain has had undue opportunity to increase.

Sheep destroy Wire-worms.

Sheep are invaluable for protecting wheat-fields from the ravages of the worm, and indeed it is scarcely possible to manage a poor and thin soil without the help of this animal. Herein lies the advantage of maintaining a numerous flock of sheep on farms composed of land of this description. The farmer will find his account in the goodness of his future crop, by driving the flock in various directions over the field after the wheat is harrowed in, so as to tread the whole surface of the ground to a degree of hardness nearly equal to that of an earthen floor; and if this practice has been neglected in the autumn, the same method may be pursued early in the spring; and these are the best means either of preserving a crop of wheat from the worms, or of stopping them in their progress where they have already seized on a field. Sheep may be driven upon a wheat

field in this way, even in wet weather, when the roller cannot so conveniently be used. To roll growing crops of wheat is absolutely necessary on most lands in the South of England, but particularly on light thin soils. There are no soils of this sort whereon the crop will not derive much benefit from rolling.

Other accounts agree with the foregoing statement of Banister, that it is customary to take pains to plough under the clover-sod early in the summer (sometimes in July), and to bury it as completely as possible. "The ploughing is better done early, to allow the furrow to get stale before sowing the wheat." "A stale furrow being best for wheat, the earlier in the season clover-sod is ploughed before sowing the wheat, the better and firmer the land is for the purpose." In some cases the land is rolled a month or six weeks after the sod has been ploughed under, and is then left at rest until harrowed for sowing the wheat. Several other writers beside Banister have argued that the compression and the careful burying of the sods are specially useful on calcareous soils that are subject to grubs and wire-worms, in that these vermin are deprived of the food and shelter which would be afforded by the scattered sods which would be left upon the land if it were ploughed late in the season. It is important, of course, to allow time enough for the sods to putrefy before the wheat is sown, otherwise the seed-grain might be involved in the fermentation and destroyed.

Merit of Clover on Thin Soils.

It has often been urged that better crops of wheat may be reckoned upon after mown clover than after clover which has been pastured throughout the year, and that clover which has been twice mown is better yet as a preparatory crop. The idea is not unreasonable, in view of the large number of roots which are thrown out by red clover immediately after it has been mown for hay; and, as has been said already, the investigations of Voelcker have shown that the more fully the clover is allowed to develop, so much the better. Some farmers have thought that the weight of clover-roots upon an acre of land may be more than doubled when, after the hay-harvest, the crop is left to itself to grow for a second mowing. On the other hand, it has been supposed that the development of roots is checked when the plants are constantly fed down by sheep from spring to autumn. Banister argued in his day that the leaves shed upon the land by mown clover, together with the shade cast by the plants up to the time of mowing, are sufficient to account for the fact that the soil of clover-fields is found to be in better condition for wheat after a season of mowing than after one of pasturing; but in the light of the better knowledge of to-day, it seems probable that the soil is enriched by a freer growth of nodules on the roots of those clover-plants which are allowed to grow large enough to be mown.

It is still said that on the high, dry limestone and chalk hills of Southeastern England full crops of wheat can only be grown when the land has borne good crops of clover, either by itself or admixed with grass. Barley will succeed on these lands after turnips, but it is only upon sod-land that wheat can succeed fully when the texture of the soil is light. Instances are cited of light soils on magnesian

limestone which will not yield good crops of wheat after any other crop than clover or a mixture of clover and grass. But it is very noticeable, in regard to these light chalky and gravelly soils, that special pains are taken to consolidate the land after the sods have been ploughed under. After the clover-sod has been turned under, with a flat, shallow furrow, the land is rolled heavily before the wheat is sown. Recourse is again had to the roller after the seed has been sown, and to treading and folding with sheep, in order that the land may be properly firmed. In this way a firm and compact bed is obtained for the seed-wheat, and the sod furnishes, by its gradual decay, a continued supply of food for the wheat-plants, while the risk that the crop may be thrown out is lessened, and the ravages of wire-worms are checked. Among rolling implements, the clod-crusher was said to be specially esteemed, because it dints the ground as a flock of sheep would. Before the introduction of the ring-roller and the clod-crusher, it was customary on many light lands in England, at the time of sowing wheat, or barley in the spring, to herd all the young and lean cattle of the farm, and to drive them to and fro over the land, after the harrows, to consolidate the soil. This trampling was made as methodical as possible, the whole field being gone over ridge by ridge as fast as the harrowing was finished. This practice, it will be noticed, differed somewhat from the folding of sheep at night in preparation for wheat, for the sheepfold supplied manure beside consolidating the soil.

It is to be remembered that the earliest European system was always to sow wheat on a bare fallow. The practice of sowing on clover-sod was comparatively speaking a modern innovation, which in some regions has always been thought to be inferior to a practice of sowing wheat after a fallow-crop that has been harvested or consumed upon the land early in the summer. It is said that the need of sowing clover in order to secure a full crop of wheat was never so much felt on clayey soils, even in dry climates, as on those of lighter texture.

Wheat after Root-crops.

Instances are occasionally reported where wheat fails after clover. Thus, it has been said that on the deep, light, friable calcareous loams of the chalk-hills of Yorkshire, it has become an almost universal practice to sow wheat after turnips. "The reason why the earlier method of growing wheat after clover has been abandoned is, that on these soils and in this climate the wheat-plant was found to be very apt to be turned out in the spring if sown on clover-lea; it was found that no system of rolling or of treading with sheep could counteract this tendency. Upon these deep loams wheat of finer quality is obtained after rape and turnips than by any other method. But where the soils are thin, the very converse of all this takes place; wheat after turnips does not succeed well, and oats or barley are grown instead of it." Nevertheless, in a report made in 1858 upon the light chalky soils of Norfolk County, it was mentioned, as a very striking feature of the farming there, that a "Great extent of wheat is now grown. A few years ago hardly any wheat was sown after a root-crop, but it is now almost universal to sow wheat after mangolds,

and to sow a large portion of the turnip-land with it as well. The reasons for this change are, that wheat will bear high farming better than barley, and is not so liable to be affected by unpropitious seasons. Clover and sainfoin, moreover, grow much better with wheat than with barley, when sown upon these crops."

In a report upon the Scotch county of Haddington (East Lothian), written in 1873, it is said that nowadays wheat is never sown there, as it is in England, immediately upon the sod of clover or grass, and that attempts to thus grow it have resulted in failure. Yet at the close of the last century this method of cultivation was practised in some of the best districts of this very fertile county. It is said withal that wire-worms, which cause so much damage in other localities, are not abundant here, and are seldom troublesome except where old pastures are broken up. Wheat does, indeed, occasionally follow clover and grass, but only after a so-called "rag-fallow" has been made, i. e. a hay-field or defective pasture is ploughed in July, cultivated, rolled, dunged, and again ploughed, and then seeded in autumn. In Eastern France, according to Gasparin, the peasant proprietors are accustomed to pare their little clover-fields with the hoe, and to harrow in wheat without breaking up the land.

It appears, in general, that at the middle of this century wheat was grown after mangolds in England in numberless localities on moderately heavy soils. But barley was grown after wheat rather than after roots. Mr. Clarke has expressed himself upon this point as follows: "I have heard the opinion too often expressed to doubt its accuracy, that barley taken after wheat is a more even crop, and of a kinder quality for malting, than after turnips, the folding on which makes the ground too rank for barley; but what is the barley's bane is the wheat's blessing. Wheat wants manure, and that of the fold is the most economical. The treading of the sheep, too, on the soft turnip-ground is highly beneficial, especially if there should be any rain, and it consolidates the land more than folding on clover-lea would. There is no pressure like the thin, sharp, cloven feet of sheep. In Hampshire wheat thrives as well on turnip-break as on clover-lea, or better, though this is not the case elsewhere on chalk soils; and besides, there is no danger of wire-worm. . . . For wheat, deep ploughing will not do; the ground is not sufficiently consolidated, and the plant will heave in the winter frosts."

Trampling by Men.

On the peaty soils of the English fens special pains were taken to drain, to apply clay, and to roll and press the land both before and after seeding, in order to insure good crops of wheat. Just as in other districts the treading of sheep is esteemed to be an effectual method of fastening the roots of wheat, so in the fens wheat has sometimes been trodden by gangs of men and women, each treading along one drill. In this way the soil was effectually consolidated. The operation was not expensive, and on the loose vegetable soil of the fens it was more efficacious than rolling.

Another practical rule of English farmers with regard to wheat is that, unlike rye, it should not be sown when the soil is dusty. Rather than to do this, it is thought best to defer the sowing even until a

late season. It is held, in general, that a soil is never too moist for sowing wheat, provided it works at all kindly, and that the seed can be effectually covered, though of course care should always be taken to avoid stirring, when they are wet, such soils as are liable to run together, and thereafter to form hard crusts when the weather becomes dry. Markham, in 1625, directed that "rye should not be steeped, for it loves dryness, but wheat may be sown in rainy weather." Marshall mentions as a fact, "observed in many countries, that wheat never succeeds better than when the seed-ploughing is given while the soil is wet."

On heavy land in Suffolk, England, some farmers formerly gave half a dressing of dung to their horse-beans, and the other half to the wheat which followed the beans. The dung for the beans was not ploughed in very deep, as it was thought that beans require a firm bottom, and that by ploughing deep for the wheat the manure applied for the bean-crop would be brought nearer the surface. In Scotland, also, some farmers, having in view primarily the destruction of the eggs and larvæ of an insect which harbors in bean-stalks, and which might injure young wheat in the spring, are at pains to turn under the bean-stubble with a shallow furrow immediately after the beans are harvested, and to "cultivate" or harrow the land pretty thoroughly. After the lapse of four to six weeks or more, they plough again deeply, and proceed to sow the wheat. Doubtless, there are numerous instances where the hope of destroying insects or worms has had more influence in establishing an agricultural practice than any considerations directly related to tillage or fertilization.

Grain-crops need to be fed with Nitrogen.

The fact that the wheat-crop stands in special need of nitrogen has important bearings on the theory and practice of rotation. For example, if it were practicable economically to cope with weeds so effectively that a mediocre soil manured with dung could be cropped with wheat continuously, the fertilizing materials in the dung might be expended to tolerably good purpose during several years, for the nitrogen in the dung would be sufficient to enable the crop to utilize a fair proportion, though not the whole, of the ash-ingredients contained in the manure. But by repeating continually upon the same field the crops of wheat and the dressings of dung, a succession of unconsumed residues of ash-ingredients would be left in the land year after year, as long as the experiment was continued. In order to use up the whole of the ash-ingredients, and prevent them from lying idle and useless in the soil, either the manure would have to be omitted every few years, and some crop be grown which can procure nitrogen for itself, or enough of some special nitrogenized manure must be added to the

land every year, in addition to the dung, to enable the wheat to take up the whole of the ash-ingredients of the latter.

As has already been said repeatedly, it was discovered long ago by the English farmers that, for land in fairly good condition, assimilable nitrogen compounds are a proper special manure for grain-crops. It was noticed also, tolerably early, that several of the fallow crops (i. e. clovers and other legumes) can in some way, during limited periods, get nitrogen for themselves. Both these points have been repeatedly illustrated by scientific experimenters, but by no one more frequently or forcibly than by Lawes and Gilbert; and it has been shown conclusively that, while nitrates and ammonium salts are proper manures for grain, turnips are especially grateful for phosphates, and leguminous plants for potash. As Gilbert has set forth, leguminous plants, when grown in rotation with grain, etc., can often supply themselves with an abundance of nitrogen, provided the land is dressed with a potassic fertilizer, and that it contains, of course, a fair store of phosphates, lime, etc. Thus, beans grown year after year upon land that received no nitrogenous manure, but only a complex mineral fertilizer, rich in potash, took off 61.5 lb. of nitrogen per acre per year during the first twelve years of the experiment, against 48 lb. that were taken off per year during the same period by the bean-crops grown upon an unmanured plot. During the next twelve years the potassic manure gave 29.5 lb. of nitrogen per year, against 14.5 lb. from the unmanured plot. And finally, during the whole period of 24 years, the beans that were manured with potash took off 45.5 lb. of nitrogen per year and acre, against 31.33 lb. obtained from the unmanured plot. Moreover, the beans manured with potash during 24 years took off more than twice as much nitrogen from the land as was taken by either wheat or barley under like conditions.

When red clover was grown instead of beans, the results were rather less satisfactory, because clover is a ticklish crop which is very liable to fail; it is a crop that can seldom be grown continuously upon any land, and could not be so grown in the case of these experiments. But there was obtained, nevertheless, a very striking illustration of the well-known fact that the growth and removal of a leguminous crop, rich in nitrogen, is one of the best possible preparations for a grain-crop. After the growth of six grain-crops in succession, barley was grown upon one part of the

land and red clover upon another part. The barley took off 37.33 lb. of nitrogen to the acre, and clover 151.33 lb. During the next year barley was grown upon the entire field, and the barley that grew after barley took off 39 lb. of nitrogen, while the barley that succeeded the clover took off 69.4 lb. of nitrogen; or 30.33 lb. more after the removal from the land, in the clover, of 151.33 lb. of nitrogen, than after the removal of 37.33 lb. in the barley.

Moreover, the land was tested very carefully for nitrogen in a number of places before and after the experiment, and it was found in every instance that there was more nitrogen in the surface soil (9 inches deep) after the clover had grown upon it than there had been before. And this, in spite of the fact that all visible roots and vegetable matters were picked out from the soil before the analysis. It will be remembered that Voelcker, in his research, obtained results of a similar character to these.

In a similar way, Lawes and Gilbert have determined how much nitrogen was carried away from their fields during an actual four-course rotation of crops; viz. turnips, barley, clover or beans, and wheat. The experiments lasted during seven such courses, i.e. 28 years. One part of the land was unmanured, and the rest got superphosphate of lime once every four years. It was given to the turnips, which began the course. Under these conditions, an average of 37 lb. of nitrogen per year and acre was taken off in the crops from the unmanured land, or about twice as much as was taken off from unmanured land on which wheat or barley was grown continually, without any help through the interpolation of ameliorating crops.

From the land dressed with superphosphate, the average annual yield of nitrogen was 45.25 lb. per year during the 28 years. The superphosphate increased the yield of nitrogen in the turnips to a striking degree, and in the leguminous crops also, though possibly the sulphate of lime in the superphosphate may have had some influence in this case, by acting to set free potash from silicates in the soil. In some adjacent experiments, where, instead of interpolating a leguminous crop between the barley and the wheat, the land was fallowed, the total yield of nitrogen by the whole series of crops was very much less. From permanent mowing fields 40 lb. of nitrogen were carried off on the average of 7 years from the acre of unmanured land, and this amount was increased by nearly one-half on applying mineral fertilizers, manifestly because the

amount of leguminous herbage was increased on using the minerals.

In other experiments it was found that, while "ash-ingredients," consisting of phosphates, sulphates, and carbonates of potash, soda, lime, and magnesia, applied in different localities to soils which had long been under cultivation, increased the crops of wheat only to the extent of 2 or 3 bushels per acre as compared with crops taken from unmanured land, dressings of sulphate and chloride of ammonium increased the yield to the extent of from 6 to 10 bushels.

Root-crops use up Nitrogen.

It must not be forgotten, however, that there are some fallow-crops, such as beets and turnips, which consume large quantities of nitrogen in a way not yet understood. In the experiments of Christiani, where crops were grown continually on unmanured land during 45 consecutive years, it was observed that, while wheat, barley, and oats still gave moderately good crops, even towards the close of the experiment, i. e. after having been grown repeatedly without any manure, it was no longer possible to obtain remunerative crops of sugar-beets in this way after beets had been grown 3 or 4 times upon that land. It should be said, however, that Pagnoul, in France, has maintained that there are some soils on which beets may be grown repeatedly. In his experience, sugar-beets were grown without manure during 10 consecutive years on a strong, fertile soil.

As has been stated already, Lawes and Gilbert noticed that, while wheat could be grown upon their land continuously for many years with success without any manure whatsoever, the fields sown with turnips came to yield next to nothing after three years' cropping, — a result which I myself have had ample opportunity to corroborate in respect to rutabagas. Then, on applying nitrates, or ammonium salts, their wheat-crop was doubled at once, while the turnips were hardly affected at all. On the other hand, an application of superphosphate of lime, while it had little influence on the wheat, brought up their turnip-crop at once, and added one new item of evidence to the popular belief that superphosphate is the proper manure for turnips. The question arises in this case, whether the nitrogenous fertilizers offered to the turnips were of the kind really needed. It is possible, indeed, that, thanks to the presence of the phosphatic fertilizer, there may have been devel-

oped in the soil certain microscopic organisms favorable for the conversion of humus into a form of nitrogenous food fit for the use of turnips, though not fit for the use of wheat. The practical lesson would seem to be that for turnips the land should be dressed either with a compost charged with phosphates, or with half or two-thirds the usual dose of dung, together with a generous addition of superphosphate.

As Lawes has urged, the turnip is essentially a plant which requires artificial aid for its development in agricultural quality and quantity. In order to produce the greatest weight of turnips, it is necessary that the soil should be brought to the finest and lightest condition possible by mechanical means, and that it should be manured by a large and available supply of carbon and phosphates. Many years ago, Lawes insisted on the great importance of "organic manures" for turnips, i. e. of manures rich in organic matter; or rather, it should probably be said, rich in organic nitrogen. He found, for example, that "rape-cake, especially when used in conjunction with superphosphates, is an admirable manure for turnips, as a substitute for farmyard-dung." Yeast, also, applied as an experiment, greatly increased the yield of turnips; while sulphate of ammonia, applied either by itself or in conjunction with superphosphate, gave less favorable results. Ammonium salts, used upon land that was somewhat exhausted, did not restore the lost fertility; they were of little effect as regards the production of turnip-bulbs, though they increased the yield of leaves. But rape-cake applied under similar conditions gave a six-fold development to the crop proper. Mineral manures alone did good service when the land was new and charged with useful organic matter; but the superiority of the minerals was less marked after a few years' cropping, and in order to the best results organic manures should be used in conjunction with them.

So emphatic were the results of these experiments that Lawes was led to believe at the time that "the organic manure required for the growth of turnip-bulbs should be carbonaceous rather than nitrogenous." He said (in 1847), "After the early stages of the development of the turnip-plant are passed, its rapidity of growth depends upon an abundant provision in the soil of constituents for organic formations, especially of carbon. . . . To obtain heavy crops of turnip-bulbs, large amounts of carbonaceous matters should be supplied to the soil, and dung is the cheapest source of

this substance." In this point of view, the English system of growing turnips and grain in alternation, and of buying oil-cake and other concentrated foods for the purpose of procuring manure, finds ready explanation.

A French Clover Rotation.

An interesting example of a clover rotation, said to be practised in the vicinity of Nismes, on one of the most fertile tracts in France, is as follows: The course begins with lucern, heavily manured. At the end of four years the lucern is ploughed under, and wheat is grown for four successive years without any manure other than what the lucern-sod afforded; then there are two years of sainfoin, followed by two years of wheat, and so back to lucern again. Thus in twelve years six crops of wheat are harvested, and there is only one application of manure. Actually, the land is ordinarily leased for terms of twelve years, and the tenant counts on getting 4 or 5 crops of wheat from each parcel of land. The wheat is of excellent quality, and the average yield is at the rate of 22 bushels to the acre. The manure comes from the town of Nismes, and from sheep; but it is noteworthy that so much nitrogen is supplied by the roots of the leguminous crops in this rotation that it is not necessary to apply to the land all the manure which is obtained by feeding out the forage. It is customary to apply a part of this manure to vineyards. (Gasparin.)

This example is interesting as illustrating the well-known fact of experience that several successive crops of grain can be grown upon the stock of fertility supplied by an old lucern-sod, and by showing what can be done with a soil naturally fertile in a climate which permits of the crop's being taken off early enough to give ample time for the thorough cleaning of the land before seeding for the next crop. In point of fact, wheat is harvested at Nismes in June, and the succeeding crop is not sown until late in October or November, after the land has been moistened by the rains of September and early October.

The example teaches also how dependent upon local circumstances all systems of rotation must be. Manifestly no system can be regarded as perfect, excepting perhaps for a single farm or county, at some one special time. They are mere make-shifts, all of them. The burden of proof lies upon each one of the systems to justify its existence or continuance. The farmer who practises a given system of rotation is bound to show cause why he should

not change and improve it. In this particular case the chief trouble is said to be not that the soil becomes exhausted of its fertility, but that the fields would become insufferably foul if the cleansing crops were to recur less frequently.

Gasparin has called attention to the fact that on some fields near Nismes a vigorous variety of ray-grass, peculiar to the locality, is apt to interpolate itself as a volunteer crop in the foregoing rotation. At the point where wheat follows the lucern, the presence in the soil of no very large number of seeds of the grass is sufficient to start a grass-crop which ripens among the wheat and continues to increase to such an extent that when the wheat of the third year is harvested the land is found to be covered with a thick sod, which is mown the next year for hay. On the average, these volunteer grass-crops yield fully two tons of hay to the acre, though on rich land nearly four tons to the acre are sometimes harvested.

Fallow-crops are returned to the Land.

One fact of enormous importance is true of most fallow-crops; viz. that, beside the refuse they leave in and upon the land in the form of roots, or leaves, or stubble, a far larger proportion of the crop proper commonly goes back to the land in the form of manure than is the case with the grain-crops. The straw of the grain, it is true, is usually returned to the soil in the manure; but excepting as regards potash, and the supplying of organic matter for the use of various organisms which cause fermentations, straw has comparatively little fertilizing power, and the grain itself is commonly sold off the farm. A crop of turnips or of clover, on the contrary, is consumed upon the farm, so that the greater part of the nitrogen and the whole of the mineral constituents are returned to the soil.

A very great impetus was given to agriculture in several European countries when the practice became general of growing forage-crops upon the fields which had previously been left fallow, for many more cattle could now be kept upon the farms, and much more manure was available for enriching the soil. The alternation of grain-crops for sale with green crops to be eaten by animals kept upon the farm is a most conspicuous feature common to all those classes of rotation which include fallow-crops. It was from the consideration of this point that Lawes was led to urge that "A rotation of crops is indispensable in order to carry

out a system of practical and economical agriculture." He adds, "In fattening stock, but a small proportion of the nitrogen in the food is converted into the substance of the animal; the greater portion is restored to the soil as manure." The economy of the production of meat as a means of obtaining manure arises from the greatly increased value of the nitrogen in flesh as compared with that supplied in the food. Thus, for example, 28 lb. of flesh, salable at, say $3.36, would contain 1 lb. of nitrogen, while the price of 28 lb. of peas, beans, or oil-cake, containing almost the same quantity of nitrogen, would be no more than 50 or 75 cents.

Clover may improve Tilth.

There is still another important advantage to be credited to the clover-crop in certain localities, viz. its influence on the texture or tilth of the soil. It has been noticed in some of the Western States that the continual "cultivation" of Indian corn, i. e. the frequent horse-hoeing of it, has a decidedly hurtful action upon the texture of the land. It is well known that certain silts and loams whose particles are very finely divided had better not be stirred when dry, because the particles fall together and become impacted. But such a soil, when covered with clover-plants and filled with clover-roots, may be improved in this respect; and when the clover-sod is ploughed under, the admixture of organic matter may work to prevent the "dry puddling," and so bring the land into good condition again. So, too, on newly warped land (i. e. silt land) in Lincolnshire, clover is recommended as the first crop. For the soil, having recently been deposited from water, is liable to run together as mud in case of continued wet weather, and it is highly desirable to keep the land open by adding to it a certain quantity of fibre which the clover-roots supply. It was noticed in England long ago of certain clay soils,—which when repeatedly fallowed were apt to run to mud after rain, and to "set" so firmly that the seed wheat was smothered,—that the texture of the soil could be improved and the risk of puddling be very much lessened by growing grass on the land occasionally, and ploughing under the sod.

Maize a Fallow-crop.

In the fact that too frequent cultivation may hurt some kinds of land is seen one reason for growing other crops in rotation with Indian corn, at least on fine loams. In general, it may be

said, however, that maize differs widely from the other kinds of grains in respect to its habit of growth and its chemical requirements. It grows freely in late summer long after the wheat-crop has been harvested, and puts to profit the nitrates which are produced at that time through oxidation of the humus of the soil or of the manure. Indeed, for a hundred years and more maize has been classed among fallow-crops in the South of Europe. In many American localities, also, the corn-crop plays very much the same part in rotations that turnips do in England. Maize is not only a cleansing crop, as turnips are, but like the turnip it yields large quantities of fodder from which to obtain manure. A not uncommon rotation in this country, in places where wheat is still an important crop, is: 1, red clover; 2, wheat; 3, maize; 4, wheat. Usually, manure is applied for the Indian corn, rather than for either of the other crops. But in some parts of France it is said to have become customary — while manuring heavily the maize which begins the rotation — to put some manure upon the wheat also, which follows the maize.

Mr. Russell reported long ago of Illinois, that "The prairie farmers have the idea that land has new life put into it by cultivating Indian corn, though no other crop possesses greater capacities for expanding under liberal treatment, and giving a good return for manure." As has been said already, Indian corn can bear very heavy dressings of manure, and it is generally admitted by practical men that no land is too rich for it. Enormous crops of it have been grown in Southern Europe in fish-ponds, from which the water is drawn off occasionally for the purpose of getting one or two crops. Corn is best suited, perhaps, by a rich, deep, loose loam. A good place for it is on land, previously in grass or clover, which has been devoted to a hoed crop for a year after ploughing, so that the sod may be thoroughly rotted and the land made mellow. It will grow well, however, in almost any fertile soil, excepting stiff clay and undrained bog-land. In a mere bog the seeds would decay, while on harsh clay it might happen that the land would be too cold, and in no fit condition for cultivation at times when the corn most needed to be cultivated.

Analyses of the Crops of some Rotations.

In order to get some idea as to the amount of exhaustion that land (or manure) may suffer when a definite course of crops has been

grown upon it, Boussingault analyzed all the crops obtained in certain rotations which are commonly practised in Central Europe, and contrasted his results with those obtained on determining the composition of the manure that had been applied to the land for the purpose of growing the crops: —

In the case of the old three-course rotation of 1, a fallow field, manured; 2, winter wheat, and 3, spring wheat, there was applied to each hectare of land 20,000 kilos of farmyard-manure (4140 kilos. when dry), and there was harvested 10,818 kilos. of grain and straw (8386 when dry).

In terms of kilos, there was found per hectare	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
In the dry manure,	1,482	174	1,068	83	1,333
In the dry crops	3,994	459	3,390	87	457
Difference	+2,512	+285	+2,322	+4	—876

He studied also the case of a five-course rotation practised on the rather stiff land of his farm in Alsatia, which consisted of 1, potatoes, manured; 2, winter wheat, upon which red clover was sown the next spring; 3, clover cut twice, and the after-growth ploughed under; 4, winter wheat and stolen turnips; 5, oats, which usually gave a light yield and thus indicated that the land needed a new dressing of manure. This course is a common one in Eastern France. It has the merit that the land can be cleansed by cultivating the potatoes, and that the clover-sod acts as a green manuring, and a reservoir of nitrogen. The manure applied to the potatoes of the first year amounted to 49,086 kilos to the hectare, which were equal to 10,161 kilos of dry manure. The crops harvested per hectare, excluding the potato-vines and turnip-tops which were left on the land, weighed 40,418 kilos (or 17,791 kilos when dry).

In terms of kilos there was found per hectare	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
In the dry manure . . .	3,638	427	2,622	203	3,272
In the dry crops	8,383	973	7,173	251	1,011
Difference	+4,745	+546	+4,551	+48	—2,261

On repeating this trial upon a rotation which differed only in that field-beets were substituted for the potatoes of the first year, almost identically the same results were obtained.

Another rotation examined consisted of 1, potatoes, manured; 2, winter-wheat; 3, clover; 4, winter-wheat and stolen turnips; 5, peas, manured; 6, rye. The manure employed amounted to

58,900 kilos to the hectare (12,192 kilos when dry), and the crops harvested weighed 46,566 kilos (or 23,330 when dry).

In terms of kilos there was found per hectare	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
In the dry manure . . .	4,364	512	3,146	244	3,926
In the dry crops	10,950	1,269	9,405	354	1,353
Difference	+6,586	+757	+6,259	+110	—2,573

Finally, there was studied for the sake of the contrast, the case of a field where Jerusalem artichokes were grown continually, as is the custom in Alsatia, where the crop is considered one of the most productive that can be grown. Every second year the artichoke land was dressed with manure at the rate of 45,450 kilos to the hectare (9,408 when dry), and there was harvested during the two years, on the average, 52,880 kilos of tubers and 2,820 kilos of stalks (35,562 kilos of dry products). In terms of kilos per hectare:

There was found	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
In the dry manure . . .	3,368	395	2,427	188	3,029
In the dry tubers and stalks	15,988	1,964	15,988	274	1,257
Difference	+12,620	+1,569	+13,561	+86	—1,772

These experiments illustrate anew the familiar facts that the carbon and oxygen in plants come from the air and the hydrogen from water. In all cases, more nitrogen was carried off in the series of crops than had been applied to the land in the manure, and this fact is conspicuously true of those rotations which contained ameliorating crops. The inferiority of the old three-course rotation in this respect is well marked, and it is evident that this rotation could not be maintained unless manure were obtainable from some other source than the crops grown upon the land. Practically, the manure came from fodder grown on wild pastures and meadows, as has been said.

The great excess of ash-ingredients in the manure over the amount of ashes taken off by the crops is remarkable, but it is to be remembered that much of the ashes of manure (and of plants also) is "accidental" and of no use to crops. Manure is in one sense the residue obtained by partially burning plants, and it will, of course, contain their incombustible impurities. This truth is illustrated by the following calculations made by Gasparin from Boussingault's analyses, for the sake of exhibiting the quantities of the several ash-ingredients which would have been put upon

the land in the manure and carried off in the five-course rotation above described, and in the tubers of the two crops of artichokes which, as he argued, might be supposed to have followed the crops of the five-years' course. His figures are given in the following table, in terms of kilos to the hectare:

There was contained	P_2O_5.	CaO.	MgO.	K_2O and Na_2O.	SO_3.	Cl.	SiO_2 and Fe_2O_3.
In the manure	189	1,142	225	720	660	68	11,794
In the crops of the 7 years	154	141	74	540	45	29	426
Difference	35	1,001	151	180	615	39	11,368

The quantity of stubble and roots left by Boussingault's crops have been given on page 120 of this volume.

The Norfolk Rotation.

The somewhat famous system of rotation employed in Norfolk County in England, which at the beginning of this century was known to have been in general use for at least a hundred years, was: 1, wheat; 2, barley; 3, turnips; 4, barley; 5, clover; 6, grass, broken up after the hay-harvest in the early summer, and fallowed for wheat. This scheme is specially interesting, as showing how the systems of bare and grass fallows gradually changed to systems of growing green crops upon the fallow fields. The land received a dressing of dung for the wheat and for the turnips, and marl was added occasionally for the barley or the turnips or the wheat. By hoeing the turnip-crop repeatedly and working the surface of the sod-land in preparation for wheat, weeds could be kept within bounds. The whole system was made to hinge upon the turnip-crop, and upon the dung of animals to which the turnips were fed. By means of the clover and the grass, fodder for spring and summer feeding was obtained, so that all need of natural pastures was done away with. It is to be remarked that the introduction of clover into Northern Europe during the seventeenth and early in the eighteenth century, and the cultivation of it, naturally brought about very considerable changes in the grass rotations then customary. Indeed, clover soon came to be considered as a kind of grass, and is still regarded as grass by many farmers, even here in America. The Norfolk system was found to succeed admirably upon the light, shallow, sandy loams of that county, and the maintenance of the course was long made an essential condition in the leases of such land.

The English Four-Course Rotation.

The four-course rotation still much used in England, in regions of dry and light soils, is evidently an offshoot from the Norfolk course. It consists usually of, 1, turnips manured; 2, wheat or barley, with clover-seed; 3, clover, or sometimes beans; 4, oats, or sometimes wheat. In this rotation, the land is very thoroughly cleansed by the cultivation which precedes the turnip-crop, when the land is ploughed in the autumn and again in the spring, and pains are taken to collect and remove couch-grass and other root-weeds. Manure is applied before sowing the turnips, and the hoeing of this crop serves also to clean the land. Ordinarily the turnips are fed off to sheep upon the land, which is thus fertilized for the wheat-crop.

It is said, however, that this course, excellent though it is, cannot be invariably kept up, for sometimes the turnip-crop will fail, and sometimes the clover, and whenever either of these mischances happens, the regularity of the succession is broken. The old rules of procedure were as follows. In case the turnips failed, the land was left fallow until autumn, when it was sown with wheat or clover, or it was left fallow until the next spring, and then sown with barley and clover-seed. In case the clover failed, peas were some times sown and ploughed under, or sometimes oats were sown in the clover's place, and clover in the oats' place. So, too, when it happens that bare spots are left on the clover-fields, through the partial failure of this crop, white-mustard is sometimes sown on the bare places, and the mustard is mown, together with the clover, as green fodder.

Nowadays the chief difficulty is the failure of the clover-fields. As Boussingault has suggested, were it not for the capriciousness of clover the rotations in which this crop has a conspicuous part might well be regarded as close approximations to perfection in the practice of agriculture. When red clover is sown every fourth year, the crop is apt to fail, especially on light soils; the land is said to be "clover-sick," and it is well understood that a bad clover-crop means a bad grain-crop the next year. Hence the very general substitution of other crops in the third year, so that the clover shall not recur oftener than once in 8 or 12, or even 16 years. Commonly, several kinds of crops appear to be sown in the clover's place. Thus, in the third year, one part of the field may be devoted to peas or to beans (on clay soils), and another

to white clover, or crimson clover (T. incarnatum), or sainfoin, or ray-grass. It is said, also, that Swedish clover may be grown on clover-sick land.

It has been suggested as one means of preventing the too frequent recurrence of turnips, that they might be partly replaced by mangolds by the device of sowing a given number of rows of swedes (say 12 rows) and the same number of rows of beets alternately across the field, and reversing the order of these roots when in due course of rotation the field is again devoted to a root-crop. In this way neither turnips nor beets would be repeated on absolutely the same ground oftener than once in 8 years. Each of the crops would be sown at an appropriate season, though the preparation of the land would be common to both of them. Another way of avoiding the too frequent recurrence of turnips, which is said to be frequently practised in England, is to grow kohl-rabi occasionally on the turnip-fields.

The four years' course has the merit of flexibility, in that it can readily be changed to a five years' course by seeding with a mixture of clover and grass after the grain, and letting the forage-crop stand during two years instead of one, as just stated. For light soils, adapted to sheep, the four-course rotation is well suited in England, for the animals may be fattened upon clover in the summer and on turnips in the winter; but on clay soils it is said that some modification of it, or even the six-course plan, is usually to be preferred.

Arthur Young suggested for strong, wet soils, in Ireland, that the four-course rotation might be made, 1, horse-beans; 2, oats; 3, clover; 4, wheat. Or, as a substitute for the four-course, he mentions, 1, beans; 2, wheat. In Germany, potatoes were grown instead of the turnips in the days previous to the prevalence of the potato-rot; subsequently, mangolds were grown, or sugar-beets, in the vicinity of sugar-factories. On stiff clay land it was formerly not uncommon, in some parts of England, to have, 1, wheat; 2, bare fallow; 3, oats; and 4, clover. But with the introduction of improved methods of draining, of clod-crushers and steam ploughs, the tilth even of the stiffest clays was made fine enough to permit the growth of turnips upon the fallow field, and by means of the turnips animals were fattened and manure produced.

Though Costly, the Four-course Rotation is Conservative.

With regard to the question, what quantities of fertilizing matters would be carried away, on the average, in the crops taken from land worked on the four-course plan of turnips, barley, clover (or beans), and wheat, Lawes and Gilbert have assumed, for the sake of the argument, that the products sold off from an acre of land in the four years will be 30 bushels of wheat, 35 bushels of barley, and the meat obtained from 10 tons of swedes and from clover equal to 6,000 lb. of clover-hay (or 1,500 lb. of bean-corn). They admit, furthermore, that the straw of the grain-crops, and the dung from the animals that have eaten the roots and clover and beans, are retained upon the farm, and returned each year to the land. Whence it appears that the average annual loss per acre by the sale of grain and meat will be from 4.5 to 5 lb. of potash, and from 7 to 8 lb. of phosphoric acid; amounts that may often, if not usually, be made good by disintegration of the soil.

So too, in respect to nitrogen, it is to be remembered that very considerable quantities are brought in from the air by the fungus on the clover (or bean) roots, and that these roots are left in the soil. Moreover, since the common practice in England is to buy oil-cake, or the like, which is fed to animals together with the turnips, the annual losses of potash, phosphoric acid, and nitrogen may really be more than made up to the land by thus reinforcing the dung and the clover-roots. The fact of observation that the fertility of land judiciously managed on the four-course system does not diminish goes to show the justice of this reasoning. Examples of the quantity of nitrogen which may be carried away from the land in the four crops have been given on a previous page.

It is noticeable that it costs much more to carry out a four-course rotation such as this, than it does to maintain a longer rotation where pasture-grass is interpolated. By the terms of the proposition, one-fourth of the land is given up to turnips, and the cultivation of this crop is expensive, while another quarter of the land is seeded down annually to clover; and every year one-half the land is subjected to the exhaustive action of grain-crops, so that upon every hand large expenses are incurred continually both for tillage and for manuring. But under the five-course system the expenses are much less: the land is in some measure sustained by the two years of pasturing, and there is no outlay during this period on account of manure or cultivation. (Russell.) There

are some disadvantages, however, in keeping land too long in grass or clover. Thus, in some regions where sainfoin is grown, it is customary to plough it under for oats, or sometimes for wheat, after three years, not because the crop has run out, but because of the sod's becoming foul, and on account of the increased cost of cleaning the land if it were left longer in sod, and because of the greater risk that the succeeding crop will suffer from the wire-worm.

It may here be remarked that sainfoin endures much longer than red clover, — sometimes for 16 or 20 years or more. Since it is apt to be choked out by grasses which grow among it, the usual limit of its profitable growth may be regarded as 8 or 10 years. On land which is not specially suitable, it may last no longer than 5 or 6 years. It can seldom be grown continuously. Marshall, writing of Central England, has said, "The duration of sainfoin on the Cotswold hills is short; seldom more than 10 years, even on land which has never borne sainfoin before. . . . The general idea seems to be that land ought not to be recropt with sainfoin under 20 years." Lucern also, in favorable situations, may endure for many years. Gasparin says that when grown for the first time on deep, moist, calcareous loams, it may last 15 or 20 years. But when sown on the same land after an interval of several years, it may not last more than 4 or 5 years. There are, in Southern France, exceptional instances where lucern grows continually for indefinite periods of time without manuring, but in such cases the subsoil is kept constantly moistened by ground-water of excellent character which percolates through the land. Even on such land, however, lucern may be choked out finally by couch-grass and other weeds, which are very apt to destroy it in less favorable situations.

A Scotch Six-course Rotation.

A six-course rotation, such as has been described on a previous page as common in Scotland and in some parts of England, is said to be well adapted to moderately heavy soils of good quality, in cases where the farmer does not need to grow so many roots as are necessary in light land districts. The six fields permit a larger area of land to be devoted to grain-crops, and the risk that the turnips or clover may fail is diminished, since neither of these crops recurs oftener than once in six years. The idea on which the system rests is, that clay soils, when well cultivated, are capa-

ble of producing wheat oftener than once in four years, provided that other crops are judiciously interpolated; whereas, on light soils, such as those on which the four-course rotation is practised, any diminution of the proportion of fallow-crops would be likely to prove unprofitable. It was suggested, none the less, by Arthur Young, that on light, dry soils suitable for potatoes in Ireland, the six-years' rotation might run as follows: 1, potatoes, well manured; 2, wheat; 3, turnips; 4, barley; 5, clover; 6, wheat.

The Ash-ingredients of Farm-manure are not well balanced.

In insisting upon a previous page that the amount of nitrogen in farm-manure is inadequate fully to balance the ash-ingredients, the argument might have been pushed still further, and the kindred fact have been dwelt upon that the several ash-ingredients of farm-manure are not present in such proportions that they can supply the wants of crops in the best possible way. This fact will appear clearly from the following computations of Heiden, who has contrasted the amounts of potash and phosphoric acid ordinarily contained in farmyard-manure with the amounts of these substances which would naturally be carried off from a Prussian Morgen (= 0.631 acre) of land by the crops grown in several modifications of a four-course rotation. Thus, the amounts taken off would be, respectively, in case the course of crops was as follows, —

	Potash. lb.	Phosph. Acid. lb.
1. Wheat	16.40	10.67
2. Oats	10.47	4.59
3. Potatoes	66.41	18.33
4. Hay	39.54	11.32
	132.82	44.81

That is to say, the proportion of potash to phosphoric acid is 2.96 : 1.

In case the crops were, —

1. Wheat	16.90	10.67
2. Barley	17.44	10.65
3. Potatoes	66.41	18.33
4. Hay	39.54	11.32
Potash to phosphoric acid = 2.76 : 1.	140.29	50.97

If the crops were, —

1. Rye	20.03	12.15
2. Oats	10.97	4.59

3. Potatoes	66.41	18.33
4. Hay	39.54	11.32
Potash to phosphoric acid = 2.95 : 1.	136.95	46.39

If the crops were, —

1. Wheat	16.90	10.67
2. Oats	10.97	4.59
3. Mangolds	148.54	25.62
4. Hay	39.54	11.32
Potash to phosphoric acid = 4.13 : 1.	215.95	52.20

If the crops were, —

1. Rye	20.03	12.15
2. Barley	17.44	10.65
3. Mangolds	148.54	25.62
4. Hay	39.54	11.32
Potash to phosphoric acid = 3.78 : 1.	225.55	59.74

Actually, in a 10-years' rotation at Waldau, consisting of bare fallow, winter rape, wheat, peas, rye, potatoes, summer fallow with clover and grass or barley, mown clover, pastured clover, and rye, the crops carried off 263.1 lb. of potash and 120.8 lb. of phosphoric acid (i. e. 2.16 potash to 1 phosphoric acid).

But in 100 pounds of fresh farmyard-manure, Wolff found 0.538 lb. of potash and 0.129 lb. of phosphoric acid. The relation between the two being 4.17 : 1. And Schmid found in manure from stables of neat cattle in one instance 0.461 % potash and 0.126 % phosphoric acid (3.66 : 1), and in another instance 0.556 % potash and 0.074 % phosphoric acid (7.51 : 1). From all of which it appears that cow-manure does not contain potash and phosphoric acid in the proportions taken by the crops cited. Hence the liability, on the one hand, of failing to supply a crop with enough of some one kind of food, and the risk, on the other hand, of dosing it with an undue excess of another kind of food.

The figures illustrate (in the cases of potatoes and mangolds, in particular) the importance of rotation considered as a means of putting to profit by means of appropriate crops any constituents of plant-food (potash in this case) which may have accumulated unduly in the soil; and they enforce the lesson that it is often well to reinforce the manure of the farm with small additions of special fertilizers in order to meet the wants of particular crops. This illustration shows, moreover, how vastly important the manure really is in these rotations, in spite of all its defects in respect to

proportion, as a means of carrying back to the land great quantities of fertilizing materials, which are regained, as it were, by feeding to cattle the fallow-crops and the straw of the grain-crops.

It is interesting to note how much more potash than phosphoric acid was taken from the land by the crops here cited, and to speculate as to how long the soil could have continued to supply this potash, or the phosphoric acid either, in case dressings of dung were no longer applied to it. As regards the farm at Waldau, above mentioned, it is known that during many years more than enough manure had been put upon the land than would have sufficed to supply all the ash-ingredients taken up by the crops.

Modern Rotations.

Most of the modern systems of rotation in connection with high farming depend, like the systems last alluded to, upon the alternation of straw-crops and leaf-crops, or, as the old terms were, "white crops" and "brown crops," to the exclusion of pasture-land. They are remarkable chiefly because of their elasticity or capacity of admitting a great variety of crops. The farmer is thus left comparatively free to choose whether he will grow more or less of any one of his crops in a given year, according to the indications of the market. Thanks to better systems of tillage and to the use of fertilizing materials brought from without, courses of rotation, as they improve, tend more and more to free the farmer from rigid bonds, and to bring him back to no system other than that dictated by the prices of produce and of fertilizers in the markets of the world. In making this statement, it is not meant to imply that the idea of rotation will ever be given up, for there can be no doubt about the importance of attending to it. But it is certain that the old notion of adhering inflexibly to given courses of crops through terms of years has lost much of its former significance.

An interesting example of free action was reported some years since, by Morton, in England, in describing the successful conversion of a large tract of pasture-land to arable. After the land had been drained and pared and burned, as he said, "Every other year every field on the farm has borne a crop of wheat; and on the alternate years the crops have been successively clover, turnips, carrots, clover, mangolds, and potatoes." The roots, etc., reinforced by oil-cake, oats, and beans, were consumed with and on the straw by cattle, sheep, and hogs, whereby large quantities

of manure were obtained to be applied to the fallow-crops. Under this treatment the land received almost every year thorough tillage and cleansing, and the manure obtained counterbalanced the products sold. Indeed, after a few years, the straw of the grain-crops became so bulky that it seriously interfered with the produce of grain. The wheat lodged, and the yield of grain was lessened in consequence of the luxuriant growth of the crop. To avoid this difficulty, it was proposed to take a crop of merchantable horse-beans occasionally, in place of one of the forage-crops.

It is evident that soils naturally fertile may be kept up in this way, even to a high pitch of productiveness, in spite of heavy sales of farm produce, for the frequent tillage insures a good supply of capillary water, as well as nitrification and disintegration of the dormant fertilizing matters which the soil holds in store, and the heavy dressings of manure maintain a great reservoir of plant-food in the land, while they act also to mitigate the harm done by droughts.

Nowadays Artificials Re-enforce Dung.

One modern improvement is the very frequent infringement upon the old plan of putting the whole of the manure allotted to a rotation on one crop. The artificial fertilizers enable the farmer to supplement his supplies of dung so easily that it is now thought to be best to dress the fields frequently, even if not very heavily at any one time. It is recognized, also, that some crops profit more from dung than others, which will do well with the chemical fertilizers, either used by themselves or as additions to a modicum of dung. Thus, in respect to potatoes, which in Great Britain are grown in rotation at intervals of 6, 7, or 8 years, it was customary formerly to dress them heavily with farmyard-manure at the rate of 12 or 14 or 20 or more long tons to the acre, although, as Lawes and Gilbert found, the tubers remove a less proportion of the nitrogen of farmyard-manure than does any other farm crop.

But it has become customary there, in many localities, to use artificials with the manure, or even to use mixtures of artificials without any dung. So, also, with mangolds and horse-beans, the farmyard-manure is often supplemented with 2 or 3 or 5 or even 10 cwt. of a mixture of artificials. Even for turnips, a common plan is to apply 10 or 11 tons of manure together with a strong dose of superphosphate, as has been stated already. In some Scottish localities, where the growing of early potatoes is an im-

portant branch of farming, all or most of the farmyard-manure is applied to this crop. Large quantities of turnips are grown also, but chiefly with artificial fertilizers; yet, on passing to districts where less attention is given to early potatoes, it is noticeable that the turnip-crop is there treated to a mixture of artificials and dung.

It is a fact of no little interest that potatoes can bear heavy dressings of dung much better than the grain-crops can. It was noticed long ago by European farmers that potatoes grown year after year on the same land, and manured every year, give much better crops than wheat similarly treated, even when the land is well suited for the growth of wheat. It is to be remembered, however, that it has been discovered that the fungus which causes "scab" on the potato may pass unharmed through the intestines of animals, and does in fact, harbor in barnyard-manure. It is well known, moreover, that potatoes may readily and safely be grown by means of artificial fertilizers alone. From experiments and observation in England, Voelcker was led long ago to the conclusion that on light land excellent crops of potatoes may be grown at comparatively small expense without dung by means of a mixture of superphosphate, potash-salt, and sulphate of ammonia.

Circumstances that control Rotations.

The rule was at one time formulated in Germany that on the best kinds of soils the farmer may safely devote two-thirds of his land to grain-crops, and one-third to fodder-crops; that on soils of medium quality he may grow three-fifths grain and two-fifths fodder, while on poor land he should have three-fifths of the land in fodder and no more than two-fifths in grain. But naturally enough there have always been, and there always will be, various circumstances and conditions beside those already mentioned which exert no small amount of influence on the practice of rotation. Not only the soil of a farm, but the climate of a farm, may determine absolutely what kinds of crops shall be grown there, and what kinds of rotations shall be practised.

In a wet country, those soils will naturally be esteemed from which the excess of water drains away quickly after rain has fallen, while in dry regions soils which are not too permeable will usually be best. In localities where the rains are well distributed, light soils will naturally be preferred for most crops because the cost of tilling them is comparatively small; but, in point

of fact, such soils are almost everywhere liable to suffer occasionally from droughts, which unfit them for bearing many kinds of crops.

In Central Europe, sandy soils are generally regarded as well suited for the growth of rye, barley, oats, peas, flat turnips, and other hoed crops, and especially for potatoes, but not for winter wheat; while on clayey soils good crops of winter wheat, horse-beans, mangolds, cabbages, and clover may be counted on. But, as a general rule, neither rye, barley, oats, spring wheat, potatoes, turnips, nor other root or garden crops, can be expected to do well upon clay. Fruit trees also, standing in clay, are apt to be sickly, and to suffer from frost.

In writing of the sandy and clayey soils of Maryland, Milton Whitney has said, "The strong clay soils here spoken of are not lacking in any particular plant-food required by a crop of sweet potatoes or of cantaloupes, yet these crops cannot be successfully grown on them. They contain all the elements of plant-food needed by a crop of tomatoes, but the tomato-vines would be large and bushy — they would be late in maturing, and the yield would be small in proportion to the size of the plants. All kinds of truck would be late in coming to maturity. These are sure signs that the soils have retained too much of the rainfall for the best and earliest development of these crops. The conditions are favorable for grass and wheat, for both of these crops require a long and slow period of growth so that they can put on a large amount of foliage before it is time to ripen a crop. The light, sandy truck-lands, on the contrary, will not grow a large crop of grass or wheat because the conditions are not favorable [in this locality] to the slow growth required by these plants to produce foliage to gather food-materials from the soil and air, for the crop is forced to maturity before it has attained any size. With good treatment, this light land would not bring over 4 or 5 bushels of wheat to the acre, while the heavier clays would yield from 25 to 40 bushels."

In England, the importance of the horse-bean as a preparatory crop for wheat, on moist clayey land, has long been recognized in districts where the potato could not be grown with profit on such land; while in regions of lighter soils the potato might be preferable.

In peaty soils, oats, carrots, rutabagas, and rape usually do

well. It is recognized, however, that the foregoing views concerning soils depend largely upon climate. The rutabaga, for example, grows well enough on clays in Scotland.

Influence of Weather.

It has been said of wheat that the soil proper for it is that which can hold water enough to supply the crop until the moment when the grain begins to ripen. In South Germany, where comparatively little rain falls, it is only the heavy soils which can fulfil this condition ordinarily, and such soils are called wheat-land there. But in Holland, and on the West coast of England, where rains are frequent, the farmers prefer to sow wheat upon lighter soils; for, though fond of moisture, the wheat-plant cannot bear undue wetness, especially during the later stages of its development. These considerations bear directly upon the question, What crop shall precede the wheat? At Paris, as Gasparin has set forth, it was a risky matter to try to grow winter wheat after the late-ripening potatoes of former days, simply because in the rainy autumn weather the land was seldom in a proper condition to be prepared for the wheat. At London, as he pointed out, matters were apt to be still worse, because it is even more rainy there in October than it is at Paris; hence it is only on light sandy soils, little retentive of moisture, that winter wheat can there be grown after roots. But at Orange, in the South of France, where there is much fine weather in the autumn, winter wheat can be grown readily enough after late potatoes.

He suggests the rule that winter wheat should not be sown after root-crops in localities where the rainfall exceeds the evaporation during the period which intervenes between the harvesting of the roots and the sowing of the wheat, because in this event the land cannot be prepared properly for the wheat. It is to be inferred from this suggestion that in the vicinity of London and Paris, spring wheat might be grown after late potatoes, beets, and carrots, and that winter wheat should succeed such crops as turnips, peas, or clover, which are harvested comparatively early.

In the Southern States of this country, M. Whitney has observed of several crops, and particularly of cotton, that "In heavy clay soils the supply of water may be so abundant as to prolong the growth of the plant [unduly] and increase the size and yield per acre, while greatly retarding the ripening of the crop." He says that in some parts of Maryland, wheat and tobacco are

commonly grown on the same land, in alternate years, or in longer rotation, although it is recognized that the strongest and best wheat-land is too heavy for tobacco. Under these conditions, the tobacco gives a large yield, but makes a coarse, thick leaf. The best class of tobacco-lands is of lighter texture, and too light for the best wheat production. "In the uplands of South Carolina and of Maryland, a soil must contain at least 20 % of clay to be 'strong enough' for a good wheat-land. Soils containing less clay than this are excellent for the light-colored tobaccos, for fruit, and for early truck, though rather too light in texture for the economical production of wheat. The finest wheat-lands contain from 30 to 35 % of clay. Under the prevailing climatic conditions, the soil must contain at least 25 or 30 % of clay for a good grass-land, and soils containing less clay than this are [there] too light in texture for a permanent sod of grass. Limestone soils, like those of the Cumberland valley and the famous 'blue grass lands,' have from 40 to 50 % of clay." . . . "On the light sandy soils of Maryland, the conditions are, as a whole, unfavorable to wheat and grass, but these drier conditions are distinctly favorable for forcing crops to an early development, and this gives them great value for early truck. By forcing vegetables to an early maturity they are put on the market two or three weeks earlier than they can be produced on the heavier soils of the State, and they bring a higher price."

The influence of climate in determining what crops shall be grown is well illustrated in the case of rye. In many Northern countries rye is an important crop, not merely because it can be grown on poor sandy land, but because it can withstand the winter's cold. In New England, it is grown not only for the sake of its straw and grain, but often also as a forage crop, to be mown green in early spring for feeding milch cows. But, as Gasparin has pointed out, either oats or barley might be preferable to rye for this purpose in countries warm enough to permit of these crops being sown in the autumn, for both of them yield softer and better fodder than rye does.

Turnips need Moisture.

Since turnips of all kinds succeed best in humid climates, this crop grows exceptionally well in Scotland, and at the North of England, in New Brunswick, and on Cape Cod. As Lawes has said, it can hardly be doubted that turnips can be grown in Scot-

land of finer quality, and at less cost, than in the middle and South of England, or that the South of England is better suited for wheat than the North. Yet it is still true, speaking generally, that the low temperature and abundant moisture of England is well suited for the turnip-crop, though not particularly adapted for the growing of wheat of good quality. It has been reported by English farmers that turnips, either Swedish or flat, will never grow freely until the temperature of the soil, at one foot below the surface, is not less than from 52 to 55° (F.) In the southeastern counties of England, where the climate is comparatively dry and warm, not turnips, but field-beets, are grown in great perfection; though in general this part of the island is devoted to the cultivation of wheat, barley, and beans, rather than to that of roots and green crops.

In a somewhat similar sense, it has been insisted by some writers that the reason why turnips are grown in Norfolk County is not so much that the climate is suited to this crop, as that the soil and climate are particularly well adapted for wheat and barley. Turnips are grown there, at no little cost, as a means of getting wheat and barley. But in districts improper for these grains, it would be impracticable to devote much land to the cultivation of turnips, because the introduction of this plant to a rotation would necessitate a corresponding increase in the breadth of land devoted to the grain-crops. It has been urged by Russell, as well as by Lawes, that the cool and moist climate of Scotland and the West of England is far more suitable for turnips than the climate of Norfolk is. But in no part of Scotland is one-quarter of the arable land devoted to turnips, as is the case in Norfolk; and in the West of England, as in Ireland, turnips have never been cultivated to any great extent. The fact is simply that the wet-country farmers cannot afford to grow many fields of turnips, because they are not able to get profit from any great breadth of grain, and because they have an abundance of grass for feeding their animals.

Repeated efforts were made at one time to introduce the Norfolk turnip husbandry into Ireland, where it was found that turnips grew well enough, and were well suited to help along the fattening of sheep and cattle, but that under the conditions which then prevailed they were hardly needed, because the warm, damp climate of a good part of the island permitted grass to grow and animals

to be pastured upon it during the winter months. According to Arthur Young, the true plan for the Irish farmer 100 years ago would have been to grow turnips enough to fatten in the winter as many sheep and neat cattle as could be reared on wild, outlying pastures in the summer.

Ireland a Grazing Country.

To repeat, it has been noticed in England that the comparatively dry climate of the Southern and Southeastern parts of the island has led to the cultivation of wheat, barley, and beans, rather than to that of roots and green crops; and, on the other hand, the moist summers of the West of England and Ireland are excellent for grass, oats, turnips, and rape, though not favorable for wheat, barley, peas, and beans.

In the words of Arthur Young, "The amazing tendency of the soil to grass points out in the clearest manner the application of the soil in Ireland most suitable to the climate. But this moisture, which is so advantageous to grass, is pernicious to wheat. The finest wheat in Europe and the world is uniformly found in the driest countries; it is the weight of wheat which points out its goodness, which lessens per measure gradually from Barbary to Poland. The wheat of Ireland has no weight compared with that of dry countries, and there is not a sample of a good color in the whole kingdom. The crops are full of grass and weeds, even in the best management, and the harvests are so wet and tedious as greatly to damage the produce; but at the same time, and for the same reason, cattle of all sorts look well, never failing of a full bite of excellent grass; the very driest summers do not affect the verdure as in England." It is a common remark to-day that the luxuriance of foliage at the South of Ireland fills New Englanders with amazement. Sweet-pea-vines, for example, are said to grow there to at least three times the size of ours. The mild temperature, and the great humidity of the air, acting upon a rich, open calcareous soil, are peculiarly favorable for the growth of leafy plants. As Arthur Young has said, "The worst circumstance of the climate of Ireland is the constant moisture without rain. Wet a piece of leather and lay it in a room where there is neither sun nor fire, and it will not, in summer even, be dry in a month." The mild winters, moreover, of Ireland and the West coast of England have been found to be specially favorable for the growth of early spring forage, such as rye and vetches, and for some kinds of

early vegetables. But differences such as these, as regards the relative amounts of grain and forage produced on a farm, will naturally lead to the keeping of different kinds and amounts of live stock; and so to the production of different kinds of manure, and to unlike arrangements both as regards the amount of labor employed and the kinds and order of the rotations. The climate of any mountainous or elevated district will commonly favor grass and oats or rye, rather than maize or the other grains.

In respect to lucern and sainfoin, Arthur Young noticed that they grew well in the South of Ireland, but that the natural grasses grew better and "got much ahead." "Such is the luxuriant growth of the common grasses in Ireland that there is the greatest difficulty in keeping lucern or sainfoin clean."

Soil-texture may Counterbalance Climate.

Lawes has said that if he could depend upon a constant climate in England, similar to that of the year 1846, he could produce annually 40 or 50 bushels of wheat to the acre with the same facility that he now gets 33 or 34 bushels; but that if he were to supply, in a cold, wet summer, the kinds and amounts of fertilizers necessary for the production of 50 bushels of wheat, the crop would probably run to straw and lodge. It is because of this risk that the climate will not bear out their abundant manuring, that the English farmers greatly dread a wet summer. While the average yield of wheat during 32 years of the experiments of Lawes and Gilbert was rather more than 13 bushels on unmanured land and nearly 33 bushels on land heavily manured with artificials, it happened occasionally, in unfavorable seasons, that no more than 5 and 20 bushels, respectively, were harvested, whereas, in favorable years, the yields were 17 and 56 bushels, respectively. As Milton Whitney has well said, one lesson to be drawn from these figures is that if a farmer has two soils in adjoining fields so different as to texture and in their relations to moisture and heat as to maintain conditions of moisture and heat as unlike as were those which obtained in the seasons that gave Lawes and Gilbert the above-mentioned exceptional crops, it might justly be expected that in one and the same year the yield from the two soils would be as different as the extremes noted by these investigators.

The position in which one or another crop is placed in a rotation often differs with the climate. Thus it is noticeable in some of the moister districts of Great Britain, that two grain-crops are

often grown in succession, instead of having a great breadth of land devoted to green crops. Thanks to the abundant supply of moisture, grain can be grown there with a comparatively small expenditure of manure; and, for the same reason, barley will frequently lodge in these regions when grown after turnips on good land. In these moist localities, wheat is said to thrive best after a bare fallow, or after a hoed crop, while in those parts of England where the climate is comparatively dry, wheat does best after clover or sainfoin. According to Mr. Russell, wheat sown after green crops, such as potatoes or turnips, produces healthier plants and better grain in the humid districts than when sown after clover or grass. The moister the climate, the more "natural" do light, sandy soils become for the growth of wheat. Throughout Scotland, Ireland, and the West of England, wheat is a somewhat precarious crop after clover or grass, and oats are generally substituted for it. Hence the definition of oats given by the great lexicographer: "A grain, which in England is generally given to horses; but in Scotland supports the people." One reason why wheat does not succeed well in these localities is the great vigor of the grasses in moist climates. It is not easy to clear them out from the soil, and they grow up to interfere with the wheat-plants; whereas oats, when sown thickly, smother the grass, and in some districts of England oats are sown after grass purposely to clean the land, and to fit it for bearing wheat the next year. Moreover, the straw of wheat that has been sown upon sod-land is apt to suffer in moist seasons in England from disease, perhaps because it grows rank. According to Mr. Russell, however: —

"All our Scotch and English notions respecting the qualities of soil best fitted for the wheat-plant are in great measure set aside in North America, where the climate is entirely different. There the winter is so cold that the plant is completely checked in its growth until the summer bursts in at once. This season sets in hot as well as moist, and soils of light texture can sustain the growth of the wheat-plant. Sandy soils thus become, in the eyes of the American farmers, quite natural for wheat. On the other hand, those which contain vegetable matter in large proportions are wholly unfitted for the growth of wheat, as it becomes too luxuriant and liable to disease."

Forcing Effect of Hot Climates.

As illustrating the influence of climate on the growth and yield

of crops, Milton Whitney calls attention to the average yield of wheat (15 bushels to the acre) and of maize (33 bushels) in Mass., N. Y., and Pa., in the year 1889, as contrasted with that of Ga., So. Carolina, Ala., and Miss., for the same year, viz. wheat 6 bushels and maize 11 bushels. The moist air, high temperature and abundant rainfall of the Southern States favors a rank growth of straw, and thereby hinders the production of grain. "Still further south these differences increase, and in tropical countries there is a very rank growth of vegetation, with naturally small grain production."

As Abercromby has said: In the greenhouse climate of the Equator, Nature gives a plant no rest; it is always in a forcing-house. Plants which are accustomed to a cold winter, here run all to leaf and rarely mature their seeds, — the potato goes all to haulm, and has few or no tubers, while the turnip grows nothing but leaf, with an insignificant bulbous root. It follows necessarily, from considerations such as these, that the influence of climate is often much more pronounced than that of manures. "Not only is the effect of fertilizers very largely dependent upon the season, as is very generally recognized, but even under the very best conditions, and with long-continued applications of the fertilizer, the effect of the latter is not so great as the differences in the climatic conditions of different seasons, of not at all exceptional character, appear to show." (M. Whitney.)

In thinking out schemes of rotation, the farmer will naturally take into account the influences — as already set forth — which different crops might exert to improve or to injure the land. On a light soil, the too frequent recurrence of hoed crops would be apt to consume the humus rapidly, while the occasional interpolation of a grass (or clover) field would preserve the humus. With regard to heavier land, the question of preserving humus might be wholly subordinate, and the frequent stirring of the soil particularly advantageous. In some situations, such land might well be given over to hoed crops, i. e. to crops that may be freely manured, and which require that the field shall be ploughed not infrequently.

An Example of Chemical Influence.

An interesting example of chemical influence is seen in the pains that are taken in some localities to manage tobacco-land in such manner that little or no chlorine, but plenty of potash, shall get

into the leaves of the crop. The tobacco farmer should avoid those fertilizers and manures which contain chlorine, and, according to Nessler, one way of accomplishing this result is to use only the manure of neat cattle which have been kept upon foods that are comparatively free from chlorine, such as potatoes, mangolds, or turnips. Strictly speaking, the leaves of the beets and turnips should not be given to animals whose manure is to be put upon tobacco-fields. It might even be well not to give the cattle any salt, but to supply the necessary soda in the form of sulphate of sodium. The manure of horses, sheep and swine is less suitable for tobacco than cow-dung is. Night-soil, which is rich in chlorides, should not be used by the tobacco farmer, and it will be well for him to arrange the rotations of crops so that there shall be obtained an abundance of fodder free from chlorides wherewith to produce manure, animals, animal products, and merchantable crops of kinds which will not carry away much potash from the land.

Thus, in South Germany, in addition to tobacco, there might be grown hemp, rape-seed, and the cereal grains to be sold, together with animals, milk, and milk products. On the other hand, fodder-corn (maize), beets, lucern and clover, might be objectionable in a tobacco rotation, because they take up large quantities of potash; though this danger could be done away with in case circumstances should permit the farmer to apply large quantities of potash compounds of suitable kinds. Low-grade potash salts should not be applied even to the mowing-fields of a tobacco-farm, lest the quality of the manure be injured. Wood-ashes might be put upon such fields, and sulphate of potash, or the double sulphate of potash and magnesia, could be put upon the arable land, while either nitrate of potash or pure nitrate of soda might be used on occasion to enliven tobacco-plants that were suffering from too much wetness.

Catch Crops, or Stolen Crops.

The influence of climate is seen very conspicuously in respect to the so-called "catch crops," or "stolen crops," which are grown in many localities during the latter part of summer on fields where a grain-crop has just been harvested, and where a spring-sown crop is to be grown next year. In warm countries, where irrigation is practised, a great variety of stolen crops are grown habitually. Thus, in Italy and in Southern France, crops of millet,

beans, potatoes, early varieties of Indian corn, beets, etc., may be got after the wheat harvest, to say nothing of fodder-corn, or oats, vetches, and other forage-crops which are mown green; whereas, in the more temperate climate of North-central Europe, the farmer can make but little use of stolen crops other than turnips, buckwheat, rape and mustard. Stubble turnips have long been grown in this way in France and in Germany, and so has buckwheat in some localities. White mustard, to be mown green for forage, is commended by some English writers as an excellent catch crop in many cases; sown after wheat or oats, at the middle of August, it is said to be ready to be cut (in England) about the middle of October. In mild climates, rape sown in August or September is ready to be cut for fodder in November. But it is essential to success in all such cases that the season shall be tolerably long, and the arrangements such that the catch crop shall not interfere in any way with the crop that is to succeed it. The fact that stolen crops often save nitrates, which might be lost from the soil in the drain-water if the land were left bare, has already been mentioned on in Volume II.

The significance of stolen crops as a means of maintaining fertility has been insisted upon under the head of Green Manuring. Doubtless in many situations regular rotations might be based on green manurings obtained by means of stolen crops, with the help of artificial fertilizers. Thus, in some places an alternation between spring-sown grain-crops and stolen crops of vetches and peas might perhaps be maintained for several years without interruption, and for long terms of years by the occasional interpolation of a cleansing crop.

The growing of several successive crops in a single season is seen at its best on land devoted to market-gardening, where the system has been greatly developed. In some parts of Europe, especially on moist land at the South, forage has sometimes been obtained by growing a series of annual plants one after the other, such as rye, barley, oats, buckwheat, rape, white mustard, fodder-corn, millet, sorghum and Hungarian grass, with occasional help from fields of clover and ray-grass. One plan was to sow, once a week, from the beginning of May until July, separate pieces of well manured land with a mixture of vetches, peas, buckwheat and millet, so that during a month or six weeks the crop could be mown every day at one and the same stage of development, very

nearly; i. e. when the plants were in flower. By supplementing this mixed crop with successive crops of fodder-corn, sown by itself, it is possible to maintain cows with little or no help from pastures. Here in New England, several successive crops are sometimes taken in this way on farms where cows are soiled. For example, after winter rye has been mown for forage in May, fodder-corn or Hungarian grass is sown; and after this crop has been mown, turnips may be sown, or barley, to be mown green. But where matters are pressed in this way, no one of the crops can be expected to give a very heavy yield.

Interpolated Crops.

The power which farmers have nowadays of buying artificial fertilizers makes it easier to grow catch crops than it was formerly. It is easier, too, to interpolate a crop in a rotation than at once was. Thus, in the English four-course system, where the land was formerly left idle during the nine months which elapse between the removal of the grain-crop in August and the sowing of the turnip-crop in the following June, it has been found to be practicable in the Southern counties to occupy the vacant land with forage-crops; notably with winter-rye, to be eaten upon the land by sheep in May as a good preparation for the normal crop of that year. Vetches followed later, to be eaten on the land as a preparation for late-sown turnips. (Caird.)

A good example of an interpolated crop is seen in the case of rape-seed, as grown by the Saxon farmers some years ago, before cotton-seed-oil was a merchantable product, and before petroleum was exported from Pennsylvania. Rape is a branching plant, somewhat like a turnip or cabbage-plant in its second year, which bears a multitude of oily seeds from which lamp-oil is made. An enormous development of the cultivation of rape as a summer crop occurred in Saxony soon after the introduction of guano, and for the following reasons, as set forth by Stoeckhardt. It was found that the rape-plant is specially well adapted to be grown as the first crop after a heavy dressing of nitrogenous manure, since, unlike most other crops, it shows very little inclination to lodge under these conditions. Moreover, it leaves the land in excellent condition for the growth of wheat or rye. But since the term of growth of the rape-plant is short, and since its seeds could be sold immediately after harvesting them, the crop afforded the farmer an easy means of getting back the money he had spent

for the guano. That is to say, in three months' time after the guano was bought, the farmer had his money back and his land in capital condition for sowing his winter grain. He felt sure, withal, of getting a good crop of grain without need of applying any more manure for it.

Motives of existing Rotations.

The styles of rotation now practised in Europe are very numerous, the courses ranging from 4 to 16 or more years. But they may for the most part be thrown into a few general classes. The farmer may, according to the condition of his land and his distance from market, aim either at a strict alternation of white and green crops, or he may press matters in favor of the white crops, and occasionally grow grain twice, or even several times, in succession upon the same field.

The practice of growing grain twice in succession increased very much in England after the sale of commercial fertilizers had put it in the farmer's power to manure his fields without increasing his stock of cattle. In a report to the Royal Agricultural Society of England on the improvement of agriculture, it has been said: "Next to the economy of labor (by machines) may be ranked the increase of produce by the expedient of taking two grain-crops in succession where the land is clean and in high condition, and can bear the application of special manure, and where the terms of the farmer's lease permit him to follow a rational system of farming. The four-course system of alternate grain and green crops — wheat, turnips, barley, clover — had two great advantages: first, by alternating restorative and cleansing crops with grain; and secondly, by regular distribution of labor throughout the year. The introduction of machines, and of guano, nitrate of soda, and other ammoniacal and phosphatic manures, has now rendered the farmer comparatively independent of this alternate system of cropping."

Of course the soil needs to be deep and strong, and to be properly supplied with moisture, in order that large crops of wheat may be grown upon it year after year. Continuous grain-growing would not be justified on European farms where the soil is thin and poor; but on good deep soils the growing of grain frequently may manifestly be judicious, because it permits the land to be fully utilized. One great difficulty in high farming is, that, until means are discovered of preventing crops from lodging, it will not

do to stimulate land too highly. But when the limit of utmost profit has been reached in this direction, and it has become impracticable to grow any more grain in one year than is now grown, the next step to be taken is to get more grain in 2, 3, or any other number of years, than was got before, i. e. to grow the grain-crops in more frequent rotation. It is this method of procedure which has been made possible by the implements and the fertilizers of recent times. It has been remarked of a Scotch locality, where it has been found more profitable to grow barley instead of wheat, that the change of crop has tended to the good of the soil, and that an important incidental advantage has been gained, "because barley keeps the ground much cleaner, and does not take so much of the strength out of it as wheat."

Even where wheat succeeds clover, it is said to have become customary in some parts of England to put 10 or 12 tons of farm-yard-manure on the clover-sod before ploughing it. Some farmers prefer to apply the manure before the first cutting of the clover, while others apply it between the first and the second cuttings, and others still put it upon the clover-stubble just before proceeding to plough it under. In certain grain-growing districts in this country it is said that Indian corn, barley, and wheat are sometimes now grown in succession, the corn being well manured, and the wheat dressed lightly with an artificial fertilizer.

An excellent modern rotation in New England is to grow giant maize-stalks for one year, or sometimes for two successive years, in alternation with grass for hay. The land is manured freely for the corn-fodder, and the heavy crops which are obtained are stored in silos (or simply dried) for feeding cows. The hoeing or other cultivation which is given to the young crop kills many weeds, and the powerful growth of the maize when warm weather sets in speedily overrides all competition. Hungarian grass (Setaria Germanica) is another crop which may serve, on farms devoted to grass, to check some kinds of weeds, such for example as the wild carrot. By manuring the land heavily, and taking a crop of Hungarian, many weeds will be smothered or hindered from coming to maturity.

Rotation Restrictions in Leases.

Some of the old restrictions in English leases have, with the lapse of time, become peculiarly inappropriate. They were originally imposed on the supposition that the farm was to maintain

its own fertility directly, so to say. There was no thought, when the restrictions were formulated, that farms could ever be kept up either by buying concentrated fodders or by artificial manures. But with the advance of knowledge, the English farmers came to be largely dependent on these particular resources, and whenever they were rigidly restricted as to what crops they should grow or sell they were placed at a disadvantage.

Some leases stipulated that a tenant should not grow certain crops excepting at stated intervals; or that he should not grow more than a specified number of acres of potatoes, for example, in any one year; or that the land should be kept down to grass for two or more years; or that two grain-crops should never be grown in succession; or that neither hay nor straw nor roots should ever be sold off the farm.

With regard to the selling of straw, it has been well said by Lawes that, while the fertilizing matters in a ton of it may be worth no more than $3, the straw itself may have a market value of $12 or more. But not until very recently was the tenant allowed to sell any straw, although he might have bought with the proceeds of it four times as much manure as the straw actually contains in itself.

Examples of Modern Rotations.

Beside the modern instances where two or more grain-crops are grown in succession, there are others where numerous brown crops are striven for rather than white crops. Examples of this idea are seen where the rotations are arranged to produce as many beet-roots as possible for sugar-making; or potatoes, for starch or for whiskey; or an excess of green fodder, such as lucern or sainfoin, in regions where many cows are kept. A tobacco farmer of the Connecticut Valley has assured me that, for him, beet-roots at $6 cash the ton, which was the price offered by sugar manufacturers a few years since, would be a profitable crop, for he could grow them the year after tobacco, when the land is charged with fertilizers. As things stand, he is a good deal put to it for a proper rotation. It does not pay him, he says, to keep cattle; and neither maize nor grain pays any money profit. His land is a bottom-land on a brook; it is a fine loam, the surface being some fifteen or twenty feet from the ground-water.

For the sake of illustration, some examples of rotations from modern practice are here given. The first is an English eight years' course.

1. Clover.
2. Wheat.
3. Turnips.
4. Oats.
5. Beans, peas, or vetches.
6. Wheat.
7. Mangolds.
8. Barley, sown with clover.

Some English farmers have found it possible to get from good soils three wheat-crops and one bean-crop in a six years' rotation without exhausting the land. Thus: 1, fallow; 2, wheat; 3, horse-beans; 4, wheat; 5, clover; 6, wheat.

The eight years' rotation above mentioned admits of a great variety of dispositions in the arrangement of the crops, and provides for long periods between the recurrence of the same crops on the same land. Both turnips and clover, for example, would be more likely to succeed when thus kept apart, than if the four years' course were persisted in. The importance of this consideration has already been insisted upon, but it may here be said that in Flanders, where intensive farming has long been practised, it was noticed at a comparatively early period that it may often be best to extend rotations to such an extent that certain crops shall not be repeated oftener than once in 8, 12, or 14 years. This truth was subsequently forced upon the farmers of Norfolk County (England), when their four-course system showed signs of failure, by the difficulty of getting good crops of turnips or clover when repeated every fourth year. (Caird.)

If Clover were a Sure Crop, many Courses of Rotation would be Shorter than they are.

It has been found by numberless observers, in many localities, that the clover-crop may finally fail altogether after it has been grown at frequent intervals for a considerable number of years on the same ground. It is possible, perhaps, that this difficulty might be met by inoculating the soil occasionally with germs of the root-fungus, i. e. by strewing upon the land, at an appropriate moment, some earth taken from fields capable of bearing clover-crops. But hitherto — excepting the application of potash compounds in some particular districts — no system of manuring, of cultivating, or of cropping has been discovered which will immediately restore to the land its ability to bear clover. Hence it has become customary, in some districts devoted to the four-course rotation, to sow one-third or one-half of the wheat-stubble with peas or with horse-beans, instead of all clover, so that the same land shall bear

clover only once in 8 years, or twice in 12 years. Another plan is to sow clover every eighth year or every twelfth year, and to substitute Italian ray-grass (or sometimes sainfoin) for the clover in the alternate courses. The grass is usually pastured, and the clover mown for hay. Sometimes the rotation has been so arranged that red clover shall not be sown oftener than once in 16 years. In order to do this, white clover, trefoil (annual clover), peas, and vetches have been put in the places which red clover would naturally have occupied in case the land had not been liable to clover-sickness. Schwerz held that while vetches are, in the nature of things, a supplementary rather than a regular crop, and are conspicuously inferior to clover in situations where clover will succeed, they may none the less be extremely valuable as a means of obtaining fodder in cases where fields of clover, lucern, or sainfoin have failed. Vetches are particularly well suited to be sown at a pinch, since they require no special preparation of the soil.

In some parts of England it is believed that better turnips can be grown by alternating between flat turnips, Swedish turnips, and rape on the turnip-fields of a rotation, instead of growing swedes on each and all of these fields. It will be noticed in this case, however, that since the three crops are sown at different times, and are cultivated somewhat differently, one or another of them may afford a particularly good opportunity to clear foul land from weeds.

An example of a rotation, practised some years ago on a Belgian farm, runs as follows: —

1. Potatoes, heavily dunged.
2. Wheat, lightly dunged and some liquid manure.
3. Flax, medium dressing of dung and some liquid-manure.
4. Clover, with wood-ashes.
5. Rye, heavily dunged and some liquid manure.
6. Oats, with some liquid manure.
7. Buckwheat.

Yet another example is from a Saxon farm. It runs: —

1. Rape, heavily dunged and guanoed also.
2. Wheat.
3. Potatoes, half dunged.
4. Oats, some guano.
5. Clover, pigeon-dung.
6. Rye, heavily dunged.
7. Rape, guano.
8. Wheat.
9. Potatoes, half dunged.

10. Oats, guano.
11. Peas, heavily dunged.
12. Rye.
13. Clover, pigeon-dung.
14. Wheat, heavily dunged.
15. Beets, heavily dunged.
16. Barley.
17. Rye, half dunged and guanoed.
18. Clover, pigeon-dung.

Probably there was a good supply of potash in this Saxon soil. The significance of the pigeon-dung was probably to promote fermentation and nitrification. It may have made the clover run to leaf.

Rotations depend on divers Considerations.

Although it is eminently proper to call attention, as has been done in these chapters, to the chemical principles which are involved in one or another of the various systems of rotation, it should be insisted none the less that the student must take care not to lose sight of numerous other considerations which are of equal or even greater importance. An attempt has already been made to show how the three-course rotation was a natural outgrowth of certain social conditions. But a somewhat similar remark will apply as well to every other kind of rotation, and indeed to every known system of husbandry, from the brush-burning of the pioneer to the garden culture of Belgium or China.

Systems of rotation — like most other things in this world — have their origin in, and are maintained by, the circumstances which surround them. Every one of the existing systems has been developed by force of local circumstances, and the student must consequently be careful not to attach too much importance to the theory of any one system, or to undervalue the merit of another.

Climate, distance from market, the cost of labor, the ease or difficulty with which manure (or forage) can be procured, the general character of the soil of the district, as well as the amount of capital under the control of the inhabitants, are circumstances any one of which may determine the character of the rotations there habitually practised. In countries where farms are owned by landlords and worked by tenants, there is often a more or less intimate relation between the length of the rotation and that of the lease. Manifestly a farm lease will need to run long enough that the effects of good and bad seasons may be balanced in some sort, and reduced to an average. On this idea the leases of six years common at the South of Europe seem to have originated in the

days of the old two-course rotation, habitual in that region, when the tenant harvested three wheat-crops during his occupancy. (Gasparin.) Leases of six years were granted also in Central Europe, where the three-course rotation was practised. Here the tenant got only two wheat-crops during his term, though he got two crops of spring grain also. But when relations such as these have once been established between tenures and rotations, it is not strange that difficulties are encountered when anyone wishes to run counter to the established customs.

A Crop once Established tends to Persist.

It is noticeable, withal, that when the cultivation of one or another crop, or set of crops, has once become habitual in a region, this custom tends to persist, and to exclude other crops and other methods of cultivation. Thus, the cultivation of flax in certain countries, and that of hops or rape-seed in others, has established claims analogous to those of any other vested interest. Among other incidents, many expert manipulators of the products have been bred, and the modes of preparing and disposing of the crops have become familiar to everybody. In most parts of the United States, Indian corn has thus acquired distinct rights of precedence. To say nothing as to any superiority inherent in this crop, the familiarity of our people with the cultivation and use of maize must unquestionably hinder them from trying to grow turnips or other roots as cattle food. So, too, when the time comes for producing sugar honestly in the Middle and Northern United States, it is to be presumed that sorghum will be grown to this end rather than the sugar-beet, simply because the manner of growing sorghum is very much akin to the method of growing maize, with which every one is familiar. Conversely, there would be in many situations a serious objection at first to the introduction of a new crop, because of the difficulty of disposing of small quantities of the product to the merchants of the locality, who might not be familiar with the character of the material or with the usual methods of dealing in it.

Modern Improvements.

It is hardly necessary again to insist that most systems of rotation originated in times when there were practically no means of transporting farm-crops to any great distance, and in places where there was no opportunity to sell or to exchange many of the products of the farm. In those days each and every farm had to

provide for its own support; and several different kinds of crops had to be grown for the maintenance of a family, even in situations where the farm may not have been well adapted for growing some of these crops, and where the farmer had no proper opportunity for caring for all his crops or for acquiring real skill in the cultivation of any of them. But in recent years, — and more particularly, perhaps, in this country, — since the extension of railroads and improvements in steamships have so greatly facilitated the transportation of farm products from one region to another, — it has come to be recognized that it may often be much more profitable for a farmer not to practise the old mixed husbandry, with its alternations of several crops, but to devote his energies to the production of large quantities of one or two special crops, for which his soil and climate are particularly well suited.

Now that the farmers in so many localities have easy outlets to good markets, they are apt to find their best profit in increasing their skill and perfecting their methods of growing one or two crops for sale, and in buying for home use those crops which other men can produce more cheaply than they could grow them for themselves. The tendency of the times nowadays is that the farmer should operate in a large way, with appropriate and perfected machinery, upon some one crop, or upon a few crops, and to obtain these crops at a maximum profit either by reducing the cost of production or by taking pains to harvest products of supreme excellence, which shall take precedence of all competitors in the market.

Influence of Capital on Rotations.

With regard to the influence of capital on the practice of rotation, it is noteworthy that, while a certain amount of it was well-nigh essential for the methodical practice of any course other than an extremely simple one, neither the poor man nor the rich man (working on a very fertile soil) did much trouble himself about the doctrine of extreme regularity. The rigid courses were in fact commonly practised by forehanded or well-to-do people, situated on fairly good land, and possessing cattle enough to yield a proper supply of dung, as well as power to hire an adequate number of laborers. It is true that in certain poor sandy regions in Italy, France, and Germany the rotation of lupines with grain has been found to be a valuable resource. But on land subjected to extremely high cultivation by men rich enough to manage it pro-

perly, a rigid system of rotation would be as much out of place as complex courses on very poor land. Excepting as a means of avoiding insects or fungi, rotation has in general very little significance for the market-gardener, for example, who buys and applies manure without stint to rich loams abundantly supplied with water.

A rather curious rotation of grass, pulse, and grain is said to occur on the French island Noirmoutiers, the soil of which consists of marsh-land, rich in humus, that was reclaimed long ago from the sea. The practice there is to manure with nothing but sea-weeds and the ashes of dung. As the story goes, the rotation is

1–5. Grass, without manure, mown for hay. The yield is light, viz. 2,000–3,000 kilos. of hay to the hectare.
6. Beans.
7–10. Wheat, manured with 30,000 kilos. sea-manure to the hectare.
11. Beans, without sea-manure.
12–15. Wheat, with sea-manure, and so back to grass.

The account is manifestly incomplete, in that it fails to tell where the dung-ashes are applied. Perhaps they are put upon the beans, possibly on the grass.

An interesting system of small-way farming, based upon sea-manure, has recently been cited as common at the North of Scotland and on the adjacent islands. There are numerous "crofters," as they are called, i. e. men who hold about five acres of land on the average. They have also a right to pasture sheep and cattle on the commons, such as they are, but they get their living chiefly from the sea, or by working in England in the summer. Their usual method of husbandry is to keep three-fourths of their land in oats, and the other quarter in potatoes. But the oats are heavily manured with sea-manure, and the potatoes with cow-dung together with a little guano, since sea-manure is not good for potatoes in cold countries. The three crops of oats come one after another, and the potatoes succeed them. In some cases where the land is too wet for potatoes, oats are grown incessantly for a dozen years at a time, and are manured all the while with sea-manure. The straw of the oat-crop, together with hay, is given to animals in the winter, while oatmeal and potatoes serve as human food.

Influence of Preparatory Crops.

It may be added to what has been said already, that the influence of one kind of crop in preparing the ground for another kind is a point much insisted upon by practical men. It is evident, for example, that by growing crops which are to be hoed or otherwise cultivated, not a few noxious weeds may be killed — including many of those which the manure itself has brought in or favored — and the land thus be left comparatively clean for the grain which is to follow. But, beside the unlike powers of different crops to withstand the rankness of fresh manure, or of heavy dressings of manure, there are other marked differences noticed in respect to the influence which one crop may exert upon the success of another crop which is grown after it, or together with it, on any given field. There is no doubt as to the validity of the fact, and, in seeking to account for it, the chief difficulty lies in the embarrassment which arises from a multiplicity of plausible explanations.

For example, several of the leguminous crops are known to be excellent forerunners of grain, and, as is now known, they have particular merit because of their power to obtain nitrogen from the air through the intervention of micro-organisms which live upon their roots. It is said, moreover, of clover, that it shades the ground and moistens its surface, and so probably permits the growth of the ferment which causes nitrification; that, during its long life, it brings up much food from the lower layers of the soil; that it leaves a great mass of useful stubble, and so constitutes a green manuring; that it is eaten upon the farm, etc.

So, too, with horse-beans, which, although they do not leave much stubble, and are not necessarily eaten upon the farm, are still known to be an excellent crop to precede grain in some situations. It was observed in some parts of England, even in the days of common fields, that wheat did not do so well after a fallow as after beans. The chief merit of the beans, as well as of the clovers, is doubtless that they are capable of being supplied with nitrogen from the air; and, as the experiments of Dietrich have shown, bean-roots can corrode the soil, as it were, and bring some of its constituents into a condition fit for the roots of grain-crops to feed upon.

Meslin.

The growth of meslin also (i. e. of mixed crops, such as oats

and peas) may depend either on the corroding action of roots, on shade, or on the bringing up of food from below by one of the plants, as well as on the nitrogen-bringing action of bacteria which live upon the roots of one or the other of the crops. The merit of the custom which prevails in New England, and in many other localities, of sowing clover-seeds with timothy, depends doubtless on the fact that the clover serves to bring nitrogen to the land from the air. There is abundant evidence that two crops grown together often do better than either one of them grown by itself; and it is said, indeed, that the mixed crops often succeed well where a simple grain-crop would fail. Indeed, it might almost be said that one wheat-plant can hardly have a worse neighbor than another wheat-plant; and in growing a beet-crop, it is known that it would be a very bad method of procedure not to thin out the young plants, but to leave too many of them to grow and crowd one another.

Some Plants need Shade.

The advantage gained in hot countries in shading certain crops, by growing other plants among them, suggests the thought that possibly the shade cast by one kind of plant in a crop of meslin may have a good influence on the growth of the other plant. In many countries, the coffee-plant is purposely shaded when young by means of other shrubs which are grown with it; sometimes even the banana-plant is made to serve this purpose. So, too, in the African desert, it is customary to grow beans, melons, and other garden vegetables, in the light shade cast by the date-palm. Here in New England, it is recognized that the currant and the raspberry also prosper best when they are lightly shaded.

According to Walz, farm experience teaches that on good medium soils, suited for these plants, winter wheat and winter rye succeed well when grown together as meslin. Generally speaking, he says, the two plants do better as meslin than when grown each by itself on separate parts of the field. Yet on the selfsame land winter wheat does badly when sown after winter rye, though rye does less badly when sown after wheat. Marshall, in his day, noted a popular opinion that wheat and rye sown together are not affected by blight or "mildew." A very small quantity of rye sown among wheat was said to prevent the blight. As Gasparin has said, "The components of the two plants are not the same, and it would seem that each of them, in working to procure its own food, must act to disengage matters suitable for the other."

Oats and peas, beans, or vetches do well together, both as meslin and when sown one after the other. In some localities, clover and lucern do not do well after grain, though they are excellent forerunners of grain, provided pains are taken to compress the land firmly before the grain is sown. After flax, winter grain does not do well, though clover grows well when sown upon flax. After potatoes, summer grain usually grows well, while winter grain is apt to do badly.

In Europe, barley is often grown after wheat, but it was observed by Thaer that wheat grown after winter barley is inferior to that grown after oats sown in the spring, although the barley ripens sooner than the oats, and consequently allows more time for preparing the land for the wheat. It is said, however, that in Central New York barley is grown not infrequently after Indian corn, and before wheat, on loams which are clayey, or at the least not too sandy. It is important, however, that the land should be free from thistles and other bad weeds; and in case the land is foul, oats are commonly grown, instead of barley, between the corn and the wheat. (Geddes.)

Many Crops harbor special Weeds.

It is known, too, that many kinds of crops are accompanied by their own peculiar weeds. Indeed, it might fairly be argued from the success of meslin, that weeds are not necessarily hurtful to crops in all cases. Certain crops, under favorable circumstances, may perhaps be perfectly well able to bear the presence of some kinds of weeds. Botanists have in fact noticed occasionally of wild plants that two species are apt to be found growing in company one with the other, under circumstances which point to the conclusion that one member at least of the pair has a decided preference for living near the other. Some one particular kind of herbaceous plant, for example, is seen to choose a residence in the shade of some one special kind of tree. Indeed, as Lord Bacon tells us, "There are many ancient and received traditions and observations touching the sympathy and antipathy of plants; for that some will thrive best growing neare others, which they impute to sympathy, and some worse, which they impute to antipathy. . . . It is thus: wheresoever one plant draweth such a particular juice out of the earth as it qualifyeth the earth so as that juice which remaineth is fit for the other plant, there the neighbourhood doth good, because the nourishments are contrarie or

severall; but where two plants draw (much) the same juice, there the neighbourhood hurteth, for the one deceiveth the other. . . . Where plants are of severall natures, and draw severall juices out of the earth, there the one set by the other helpeth." One striking example of "antipathy" is seen in the injury done to trees in dry countries by crops of sainfoin, which take much water from the soil and subsoil. Instances have been recorded in which walnut-trees and even large oaks have died, apparently from no other reason than that crops of sainfoin were growing at their feet. On this account, the tenants of farms in some silk-producing countries are forbidden to sow sainfoin under the mulberry-trees.

Root-crops Sap the Land.

As has been said already, beets and turnips, unless they are freely manured, are not well adapted to precede grain, because they sap the land of its available nitrogen. A good example of this peculiarity is seen in one of the experiments of Lawes and Gilbert, where barley was grown during three successive years on land which had previously been devoted for eight years to turnips, which had received no other fertilization than a mixture of mineral fertilizers (ash-ingredients). The three barley-crops were miserable, and much inferior to contiguous crops grown after turnips which had received both nitrogenous and mineral fertilizers, and even to barley that was grown without manure after three successive crops of wheat; they were less than half as large as crops obtained on land, otherwise similarly manured and cropped, to which some nitrate of soda was added when the barley was sown. As has been already intimated, this tendency of root-crops to rob the land of active nitrogen is often put to use for mitigating the extreme rankness of fresh manure, or of heavily manured land, i. e. by growing roots-crops as preparatory crops for grain.

As an instance of a mixed crop may be mentioned the fact that even mangolds and carrots have sometimes been grown on one and the same field in alternate rows. In view of the observed fact that in fields of mangolds the outermost rows are apt to carry larger roots than the inner rows, it has been thought by many farmers that it may be good practice to have the rows so far apart that every row shall be practically an outer row, and finally, as a modification of this idea, carrots have been interpolated between every two rows of the beets. In one experiment, a part of a field was ridged up 24 inches wide, and beets and carrots were sown

upon alternate ridges, while upon another part of the field the ridges were 30 inches apart, and mangolds were sown upon all of them. All parts of the field were deeply and carefully cultivated. On weighing the crops from four-acre portions of the field, it appeared that the weight of the beets from the 30-inch rows was one-third less than that from the rows which had carrots between them. Meanwhile, the crop of carrots was superb, both as to quality and weight. In another instance, mangolds grown on all the rows gave a smaller crop than mangolds grown in alternation with carrots, while the yield of carrots was nearly eight tons to the acre. This trial was described as "a method for improving the beet-crop, and getting eight tons of carrots for nothing."

Each Crop must be kept Out of the Way of Other Crops. It is interesting to observe that the term of growth of a given plant may be of paramount influence in determining the particular position which this plant, or perhaps another, shall occupy in a rotation; and the remark is specially true of cases where, after one crop has been harvested, the land has to be made ready, or worked, with special care for the crop that is to follow. It is essential that the course of crops shall be so ordered that the plants may not interfere with one another. Each one of the crops must be kept out of the others' way. For example, the interpolation of a crop of turnips after potatoes is easier in Massachusetts now than it was in earlier days, when only late-ripening varieties of the potato were grown. But, from mere lack of time, such interpolation might not conveniently precede rye or grass, unless indeed the grass-seeds were sown with the turnips, as has been done occasionally.

Another consideration that sometimes has its influence in determining the order in which crops are grown is the necessity of thorough tillage on some soils for success with some kinds of plants. Thus, it is often thought best to grow two hoed crops in succession, in order to make the land clean and mellow for the growth of grass.

CHAPTER XXXI.

ACTION OF FIRE ON SOILS.

THERE are several distinct operations in agriculture, the efficacy of which depends upon the action of fire. There is the ordinary

brush-burning of new countries, the burning of moorland, and the burning of clay; and, most interesting perhaps of all, there is the old system of burning the sods of stiff clay soils, to which the term "paring and burning" is commonly applied.

At least three conceptions are to be distinguished in this matter of the action of fire: first, the mere destruction of masses of wood which encumber the land, as in clearing a forest; secondly, the destruction or alteration of a portion of the humus in peat-bogs and moors, and other soils containing too large a proportion of this constituent, in order to ameliorate the soil; thirdly, the roasting of a heavy clay, or of some other mineral, for the sake of altering both its texture and its chemical condition or composition; and fourthly, the cleaning of land by the destruction of weeds, insects and fungi, together with their seeds, eggs, and spores.

Clay-burning.

It will be well, first of all, to speak of the action of fire upon clay, since whatever advantages are to be attributed to such action will usually be felt to some extent in brush-burning, as well as in the paring and burning of sods. It is a well-known fact that raw clay, that is to say, clay in the state in which it is dug from the earth, is not readily acted upon by chemical agents, — not even by the most powerful acids. But it has also long been known by manufacturers of chemicals that, when the inert, raw clay is exposed for some time to a dull red heat, it undergoes change to such an extent that after the roasting it readily yields its alumina to acids. This property of clay is constantly made use of in the arts, in the manufacture of alum and of sulphate of alumina; and the fact that the clay undergoes chemical changes of so fundamental a character is undoubtedly one of the reasons why the operation of paring and burning has been found to be advantageous in agriculture.

When raw clay, which has been thoroughly dried at 212° F. and powdered, is roasted it loses weight, to the extent usually of 6 to 11 %, because very considerable quantities of water are expelled from it — the so-called "water of constitution." But at the moment of losing this water the clay suffers radical changes, both as to its chemical and its physical properties. Its consistence and its capillary power are greatly and permanently diminished. It is no longer plastic, and it cannot recombine with water, not even on being soaked for a long time in this liquid.

Indeed, it now more nearly resembles quartz-sand than it does the original clay. (Schuebler.)

Excepting peat and moorland, it has come to be pretty well understood that the process of burning is properly applicable only to clayey soils, and experience has shown that burning is by no means equally advantageous to all clays. It appears, for that matter, to be most beneficial upon clays that contain a good deal of silicate of potash and some carbonate of lime. It is believed that in such clays the lime may decompose the alkaline silicate, and liberate some of its potash, in much the same way as in a method employed by chemists for setting free potash from refractory silicates, where the powdered mineral is commingled with carbonate of lime, and then heated moderately.

All clays, however, without exception, are improved by moderate burning, in so far as their physical properties are changed in such manner that the plasticity of the crude clay is destroyed, and the mass made light and friable. Properly burnt clay falls to fine powder, and has completely lost its old power of becoming sticky and plastic when moistened and stirred. But it is essential that the burning shall be well managed, and that the fire shall not be allowed to get too hot. When clay thus changed by moderate roasting becomes mixed with that which has remained upon the field unburnt, the character of the soil will be greatly improved. It is worthy of study, moreover, whether by virtue of chemical changes induced by roasting, many clays may not become better fitted than they were before to absorb from the soil-water, and to fix potash, ammonia, and other useful bases, in a manner analogous to that of the double silicates of alumina and lime which has so frequently been alluded to on previous pages.

In any event, it is important that the clay should be burnt at as low a temperature as possible, both for the sake of the physical changes and for that of the chemical alterations, of whatever name. For in case the heat were allowed to become too high, portions of the clay would cohere into hard lumps, like bricks, that could not again be reduced powder, and the chemical activity of the burnt clay would again be lost. It is said that the success of the operation of burning may always be judged of by the readiness with which the clay falls to a uniform friable powder.

Methods of Burning Clay.

One way of burning clay is to mix it with brushwood or peat,

or soft-coal slack, and to allow the mixture to smoulder for some time in heaps or pits, or even in special kilns or stoves made for this particular purpose. It is said that faggots are commonly to be preferred to coal, both because they are cheaper, and because the soil is not burned so hard as is apt to be the case when coal is used. In burning large heaps, coal is, so to say, essential, but it is a matter of common observation that while a single ton of coal may be sufficient in the hands of some workmen to burn 50 cubic yards of clay, as much as two tons of the coal may be expended by less experienced persons upon the same amount of earth, and that they may overburn the clay into the bargain. The process is probably at its best when conducted in this way, for there will be no necessity here of destroying much vegetable matter. The clay to be burned will be taken from beneath the surface, — it may even be dug from pits, — and the fuel employed for burning it will be completely under control. The cost of the process, however, must be high, in any event, because much labor is required.

The pits or trenches in which clay is burned may be made some 2 feet deep, 3 feet wide, and 10 to 20 feet long. At first they are filled to the brim with the fuel, i. e. brushwood or peat, or unmerchantable firewood, then a layer of dried clay-clods is laid on, and gradually, as the fire burns down, more clay and coal slack, or clay and sods, or clay and brushwood, are thrown on; care being taken that a slow smouldering combustion shall be kept up, and that the fire shall not break out through the clay layer. Whenever flame appears at any point, some clay is immediately thrown there to check the fire. But too much clay must not be put upon the heap all at once, lest the fire be extinguished, and enough fuel must be mixed with the clay to insure the continuous slow burning of it. When once the fire is well started, soft-coal slack or fine coke may be used as the fuel, in case they are to be had more cheaply than waste-wood or peat; but at the beginning something more readily combustible than coal is needed.

Kilns for burning Clay.

It is said to have been customary, formerly, in some parts of England, to build special stone kilns in which to burn clay and sods; but the expense of carting such heavy materials to and from the kilns has led to their disuse. To avoid this objection, movable stoves or grates have been invented, which can be carried to the places where the clay or sods are. These grates seem to be

specially well suited for burning sods taken from headlands, or from the edges of walls and roadsides, or from waste corners of fields. On clayey soils a great deal of roasted earth can be got in this way, since the dried sods serve as fuel for burning the clay that has been dug out from beneath them.

Sometimes, instead of the old stone kilns, the mixtures of clay and sods were burned in kilns built of sods. These kilns were rectangular constructions, 12 or 15 or 20 feet long by 8 or 10 or 12 feet wide. They may be made of any width that will allow men, standing upon either side, to throw clay to the middle. The outer side walls may be made 2 feet thick and 2.5 or 3 or 4 feet high, and it was thought to be well to have cross walls 3 feet apart, 10 or 12 inches thick, and 2 or 3 feet high, in order to support the clay and fuel, and to confine the heat. Channels for draughtways, some 4 by 6 inches in the clear, were built of sods from the corners of the kiln to the centre of it, or a trench 6 inches deep was dug in the ground at the middle of the kiln, and covered with slates or flat stones. The kiln was filled with brushwood or peat, or some other cheap fuel, and fire was set on the windward side. When the fuel was in full combustion, clay, and clay and sods, were gradually thrown upon it in such manner as not to extinguish the fire nor to permit it to break out and burn freely in any one place. The drafts were closed or left open according to the wind and to the rate of combustion. The walls of the kiln were continually built up with clay, so that they should always be some 12 or 15 inches higher than the burning heap, in order to shield the latter from the wind.

The chief difficulty was to get the first clay well on fire. After that, comparatively little attention is needed. Clay sods, for instance, may be thrown on morning and evening, until the heap has become so high that they can be thrown no higher. Possibly such work as this might sometimes be done, even where labor is so costly as it is in this country. When hassocks are to be burned, for example, such as are taken from bogs in the process of reclamation, or when brushwood has to be burned where land is being cleared, circumstances may occasionally permit the farmer to roast a quantity of clay which he has had dug out for the purpose at times when work was slack. Thus, in case a patch of stiff, adhesive clay happens to lie in the midst of a good field, German writers have recommended that the clayey patch should

be rough-ploughed in the autumn, and again ploughed while wet in the spring, so that large clods may be formed. When dry, these clods are thrown into little heaps, and burned by means of wood or peat, and the burnt clay is spread upon the land. Occasionally it happens on fields of clayey land that there are patches of soil on which crops are apt to fail, and this trouble has sometimes been corrected by paring and burning the infertile spots.

Paring and Burning.

The so-called "paring and burning" of the English (écobuage of the French) is a very old process, originally practised, as a means of clearing wild heaths and moors, by the Celts who formerly occupied Europe. According to Gasparin, the Celtic method is still practised habitually on the mountains of Central France for clearing wild land. "By means of it, a superb vegetation is produced on soils which, to all appearances, would seem to be incapable of yielding anything." By making three strokes with a kind of bent hoe (called écobue), one stroke to the right, one to the left, and a third to lift out the sod, strong and skilful laborers cut out rough clods a foot and a half long, rather more than a foot wide, and four inches deep, not counting the "grass" or small bushes which covered the land, and which remain attached to the clod "much as if they were hair upon a head." The more "grass" there is, so much the better.

The clods are left lying on the land, dirt side up, until they have become dry, when they are built into numerous round heaps 3 or 4 feet high and 4 or 5 feet in diameter, care being taken that the grassy sides of the clods shall be underneath and the earth sides above. Finally the heaps are fired and left to burn during several days, the pieces which fall from the heaps being thrown into the fires until everything combustible has been consumed. In the old French practice, the ashes were collected and kept in special heaps until just before seeding the land, when they were strewn between the sides of the fire heaps. No ashes were put where the heaps of clods were burned, because grain grows better anyway on those spots than on the rest of the field.

In the Celtic practice, the sod had to be cut as deeply as the roots of the wild plants had penetrated, in order that these roots should be taken out and destroyed. By so doing, the land was thoroughly freed from all manner of "weeds" and insects, so that two or more crops of clean, sound grain could be grown without

applying any manure. Indeed, the first crop of grain was apt to lodge, but by sowing clover on the second grain, forage was got for producing manure wherewith to keep up the land subsequently. Gasparin noticed, also, that large crops of potatoes of excellent quality could be grown on land thus pared and burnt, and at next to no cost for weeding.

In England, during the last century, where paring and burning had come to be employed not as a means of clearing wild land, but for changing pastures and grass-fields to arable land, much thinner sods were lifted than those cut out by the Celts. As described by Marshall, the operation of paring and burning was as follows: —

"The bushes and other encumbrances upon the surface of the ground having been removed, the sward is inverted with the breast-plough, or 'paring-spade,' as it is termed, in sods about a foot wide and three feet long. Some judgment is requisite to determine the proper thickness of the sods. If they be pared too thick, they are difficult to burn; if too thin, the sward is not effectually destroyed, and the produce of ashes is too small. A rough, spongy surface ought to be pared thicker than one which is firm and bare of grass; and a light, shallow soil ought to be pared thinner than one which is deep and more tenacious. An inch may be considered as the medium thickness. If the sods are naked and the season moist, they are set on edge to dry; but if they are grassy, and if the season be fine, this labor may be spared."

"The method of burning is invariably in small heaps, a rod or less asunder, according to the quantity of sod. Small heaps are more conveniently burned than large, and the ashes from them are more easily spread. There are various ways of forming the heaps. The bottom is generally made in a round form, about a yard in diameter, with sods set on edge. Some persons lay on the windward side of this bottom a bough of furze, or other kindling, with the brush-end outward, covering it above with the grassiest and driest bits of sod. They then make up the heap in the form of a small haycock, keeping the sods on the inside as hollow as may be, but laying them flat and close on the outside to keep in the heat. Such heaps are set on fire by igniting the kindling. In other cases, the heaps, formed at the bottom as already described, have a chimney carried up at the middle, into

which a shovelful of live coals is thrown in order to kindle them."

When the heaps are well on fire, fresh sods are laid on from time to time, until the whole are expended, not more than perhaps one-half of the original sods being used in forming the heaps. The fresh sods are laid upon the side where the fire is strongest: they are seldom added until the fire begins to make its appearance on the outer side of the heap. When all the fresh sods have been used up, the partially burnt bits which fall from the heaps are laid upon the top, so that they may be reduced to ashes, or at least exposed to the free action of the fire. The ashes are spread as soon as they have cooled sufficiently, and are ploughed in with a shallow furrow.

Methods of Paring.

The operation of paring is said to be commonly undertaken as early as possible in the spring, it being evidently a point of importance to have the soil moist enough to permit the paring-plough to slip through it easily. The crops most in use upon land that has been pared and burnt are turnips, rape-seed, and wheat, sometimes oats, though it is seldom that opportunity to burn the sods can be got early enough in the spring for the last-named crop. Cabbages and mangolds do well also on land which has just been pared and burnt. Marshall remarks that "rape and turnips are the crops generally sown. . . . But even wheat, provided the soil and the ashes are mixed together by repeated ploughings and harrowings, between the burning season and seedtime, does not appear to be an ineligible crop."

Another way of paring the land, less costly than the foregoing, is to rib-plough an old sainfoin field in the autumn, and either to cut the ridges with a scarifier the next spring or to finish the paring then with a breast-plough. The rib-plough cuts out one-half the sods, to a depth of 1 or 2 inches, and turns them over, face downward, upon the other half, which are left undisturbed, and when a scarifier is dragged across these ribs a mass of loose sods is torn up and left upon the land, whence they may be thrown into heaps to be burned.

Marshall, writing in 1796, of Yorkshire, has said that paring and burning was at that time practised there in but few districts, and that it was applied only to the reduction of old, tough sward. He says: —

"Its effect in improving the contexture of strong, cohesive soils has escaped general notice; yet how could art devise an ingredient more likely to give openness and freedom to a closely textured soil than rough, porous, unperishable ashes? [That is to say, burnt clay.] A material of improvement which the soil itself supplies free of cost. The immediate acquisition of manure from the grass and weeds repays the expense of the operation; while the more permanent improvement of the contexture of the soil is obtained without expense. Viewed in this light, sod-burning, whatever effects it may have on light, porous soils, is in all human probability a cardinal improvement of soils of a close, clayey nature."

So too, Young, in his "Six Months' Tour," published in 1770, says: —

"Paring and burning is general throughout the North and West of England. Universal observation has proved it to be a most excellent practice, and has also proved that the idea of thinning the staple of the soil by it is false and groundless. Turnips are the crop everywhere sown after it." Gasparin, also, dwells on the fact that, after paring and burning, it is easy to grow turnips and colza in situations where it would otherwise be impossible to cultivate these crops because of the abundance of insects.

Paring and Burning Persists.

Marshall states, on another page, that the invariable method of breaking up old turf upon the Cotswold Hills, in Gloucestershire, was by paring and burning, to be followed by turnips. The practice still obtains in that region, where it was studied not many years ago by Dr. Voelcker, Chemist to the Royal Agricultual Society of England. Mr. Caird, also, in writing of the same district, mentions "a field which had been broken up from its natural state 50 years ago; it was then pared and burned, and so started with the first crop of turnips, which supported the other crops of the course. The same process has since been 7 times repeated; no manure of any kind has ever been applied, except such as arose from the consumption on the ground of its own produce, and the crops in each succeeding rotation have shown no sign of decreasing. The soil, which lies on the lower oölite formation, is very thin; but as it is said to be no more so than when first broken up. The depth must have been maintained by the ploughman, perhaps imperceptibly, bringing up some fresh subsoil after each burning."

Voelcker says that the soils upon which paring and burning is practised with the most benefit contain often much and always a fair proportion of clay; they are impervious and compact in texture, and for this reason do not readily admit air. He urges that it is precisely for the turnip-crop that the process of paring and burning is specially advantageous, and that there is little risk of the soil's becoming exhausted, since it is sufficiently enriched by the excrements of the sheep to which the turnips are fed off upon the land. With regard to the loss of humus, as bearing on the power of this substance to absorb aqueous vapor, ammonia, or the like, Voelcker says that there is really little or no need of humus on this account upon clay soils, since the clay itself is a powerful absorbent in that very sense. As concerns the cost of paring and burning, when compared with the cost of applying artificial fertilizers, Voelcker remarks merely that the process continues to be practised upon the very best of the Cotswold farms, as it has been practised for many years.

It is hardly to be supposed, he urges, that a practice so fundamental as this could be persisted in for so long a time upon really good farms, the products of which must be disposed of in the face of the competition of other farms, if it were an essentially improper practice. The act of burning not only destroys all weeds and roots of weeds and seeds of weeds, all insects and eggs of insects, all fungi and spores of fungi, and so leaves the land perfectly clean and clear; but, by the very fact that it reduces much organized matter to ashes, it supplies the turnips abundantly with phosphoric acid and potash in an easily accessible and assimilable form. We know already, for that matter, says Voelcker, that turnips profit more than grain-crops from an application of phosphatic ashes. It is a matter of experience with the Cotswold farmers that their turnip-crops are larger in proportion as the fields are more thickly beset with weeds before the paring and burning; and, in support of this observation, Voelcker has found that the ashes of thistles and of couch-grass, which abound in that region, are peculiarly rich in phosphoric acid. Indeed, the amount of phosphoric acid in these plants is so large, that as much of it is often added to the land by the operation of burning as would be contained in an abundant manuring with bone-meal. According to Voelcker, the advantage lies not only in the fact that the phosphoric acid and the potash are reduced by the burning to a con-

dition in which they can be more quickly taken up by the turnips than they could be from slowly decomposing organic matters, but in the second fact, that the entire surface-soil is thoroughly impregnated with the ashes, so that the roots of the turnips are always in contact with their food.

Naturally enough, the thought lies near at hand that, while the sole objection to clay-burning is the cost of it, there must be a very considerable loss of valuable fertilizing matter when the humus of an old field is destroyed by fire. In this case, the matter burned is not a mere waste material taken from the edges of fields, nor is it a simple mineral substance (clay) wellnigh free from organic matter, but it is a true soil, more or less rich in humus and the nitrogen compounds which appertain to humus, and it would seem that a large proportion of these things must necessarily go to waste in the process of combustion. But it is plain that this theoretical objection can have no real standing in the face of the unanimous opinion of practical and scientific men who have carefully studied the process.

Fancied Objections.

So, too, in the words of Gasparin, one matter which has tended to obscure the real merit of the method of clearing land by paring and burning it, is that farmers are apt incontinently to exhaust the cleared land by taking from it several successive crops of grain. But the very fact of its being possible to get these successive grain-crops proves that "the fertilizing juices of the soil" have by no means been dissipated by the operation of burning. It is not at all surprising that the original Celtic system of thus exhausting the land by successive grain-crops should be persisted in (in poor districts), for it must have been habitual in the beginning, when an unlimited amount of land fit to be cleared was available, and the custom arose of taking from each newly cleared piece of land all that could be got from it, and then passing on to new land, while the exhausted piece was left to itself to be recuperated by time.

It seems probable that the old custom of sod-burning on the chalk-hills of southern England — like the paring and burning of thin slices of sod from worn-out sainfoin leys, as witnessed by Marshall in the same region — served a useful purpose in that the land was cleansed, and that it received a manuring of ashes. After burning the sainfoin sod, the land was broken up to be

sown with wheat or oats, while on the chalk-hills rape was grown after the burning, for sheep-food. That is to say, in times anterior to the growing of any hoed crops in rotations, the operation of paring and burning must have been particularly useful as a means of coping with weeds. By calling in the action of fire it was possible to clean the grain land occasionally, or rather to prevent it from becoming insufferably foul.

Voelcker's Experiments.

As regards the question of the loosening of potash by the action of fire on clays, it may be said that Voelcker — on roasting, at different temperatures, some clays that contained a good deal of carbonate of lime — has observed that appreciable quantities of these clays became soluble in acids, and that the potash and silica in particular were made soluble. Thus he roasted a clay belonging to the new red sandstone formation and determined the amount of potash, etc., that could be dissolved from it by hot dilute muriatic acid, both before and after the calcination. His results are as follows: —

	Clay soil in its natural state.	Clay heated in covered vessel at dull redness for half an hour.	Clay roasted at a red heat for half an hour.	Clay roasted 3 hours at full red heat.
Water expelled at 212°	5.54	9.16	9.20	9.30
Organic matter and fixed water	3.62			
Matter insoluble in the acid	84.10	80.26	81.85	85.31
Matters soluble in the acid, viz. Silica	1.450	1.380	1.580	1.150
Alumina and iron oxide	3.070	8.245	6.090	2.970
Carbonate of lime	0.740	0.420	0.550	0.188
Potash	0.269	0.941	0.512	0.544
Soda	0.220	0.336	0.314	0.104
Phosphoric acid	0.380	0.165	0.128	....
Nitrogen	0.240	0.018	....	0.006

It is evident from these analyses that the clay burnt at a moderately high temperature was much more soluble in acid than the original clay, or than that which was superheated. It is plain, moreover, that potash became soluble to a considerable extent during the process of burning. From the crude clay, little more than a quarter of one per cent of potash dissolved in the hot acid, while in the clay burnt at a moderate heat, under conditions resembling those which occur when clay is burnt in the field, there was found more than three times as much soluble potash. On heating the clay more thoroughly the amount of soluble potash diminished somewhat.

For the sake of ready comparison, the soluble lime in each of the clays has been set down as "carbonate of lime," although there was in reality none of this compound in either of the burnt clays. It appeared indeed, that the carbonate of lime in the crude clay was all converted into silicate of lime during the process of roasting, by reacting upon silicate of potash in the clay and changing it to carbonate of potash. In the light of this evidence, it seems desirable that clay which is intended to be burnt should contain lime, and not improbable that the mixing of lime with clay before burning may be beneficial.

While he had no thought of considering the mechanical changes which clay undergoes in burning as unimportant, Voelcker was nevertheless, inclined to believe that the chief efficacy of burnt clay must depend upon the potash which is liberated and made immediately available for feeding plants. He urged that clays which contain no potash or no more than mere traces of it, can hardly be fit for burning, while clays which contain large quantities of undecomposed feldspar or of other potassic minerals will probably be found to be efficacious fertilizers when burnt. He cites the case of a farmer who had to deal with a clay soil which contained four and three-quarters per cent of potash, and said of it, "I can only speak to the fact. A soil which I found quite sterile, on which this process (paring and burning) has been used became totally changed." Since the phosphoric acid in mere clay is not rendered more soluble by burning, no special fertilizing effect can be attributed to this constituent.

In another instance Voelcker examined a clayey soil which contained a large proportion of carbonate of lime. Analysis showed in it 7.75% of water, 31.38% of carbonate of lime, 58.62% of real clay, and 2.25% of fine sand, and it gave up 44% of its constituents to dilute acid, including 0.35% of potash; but after roasting this clay very moderately, 49 % of it was soluble in the acid, including 0.77 % of potash; and after proper roasting, 54 % of it was soluble in the acid.

Struckmann also found in a slaty clay 0.78 % of potash soluble in acids before the burning, and 1.53 % of potash after burning.

In a clayey soil from Cirencester, Voelcker found the following percentage of constituents:—

	Before Burning.	After Burning, in the Red Ashes.
Hygroscopic moisture	5.98	1.18
Organic matter and fixed water	13.22	3.32
Soluble in acids: —		
Alumina and oxide of iron	12.95	18.42
Carbonate of lime	7.58	8.83
Sulphate of lime	0.43	1.15
Carbonate of magnesia	1.41	——
Magnesia	——	1.76
Phosphoric acid	trace	0.71
Potash	0.52	1.08
Soda	0.12	0.55
Insoluble in acids, chiefly clay	57.09	62.52
Loss	0.70	——

In this particular instance, the quantity of burnt soil amounted to about fifteen tons to the acre, which would make the phosphoric acid equal to 225 lb., and the excess of potash, to 188 lb. to the acre.

In another instance, Voelcker found these percentages: —

	Unburnt Soil.	Ashes therefrom.
Water	0.93	9.12
Organic matter	10.67	
Soluble in acids: —		
Alumina and oxide of iron	13.40	14.56
Much carbonate of lime, with Sulphate of lime	23.90	17.17
Carbonate of magnesia	1.10	——
Magnesia	——	0.40
Potash	0.38	1.61
Soda	0.13	0.04
Phosphoric acid	trace	1.84
Soluble silica	——	8.70
Insoluble in acids, chiefly clay	49.66	44.64

The increase in phosphoric acid probably comes from the destruction of organic matters of which it was a constituent; so long as the organic matters remained intact, a weak acid might not dissolve from them the whole of the phosphoric acid. Other researches of Voelcker on the roasting of mere clays at different temperatures have shown that less phosphoric acid could be dissolved out from the roasted products by acids than from the original clays. It was found, too, that while considerable amounts of potash were made soluble (in acids) by moderate roastings, some of that which had become soluble in this way passed again into the insoluble state on strongly heating the clay. Whence it ap-

pears that it is indispensably necessary to maintain a low temperature during the process of burning. One device for lessening the risk of overheating the ashes is to perform the operation of burning in small heaps, and to take care that the sods are not too dry. It is to be presumed, in any event, that the success of the burning must depend in no small measure upon the skill and experience of the workmen; but this statement might be made of any other agricultural operation, from ploughing down.

The paring and burning of pasture land was at one time commonly practised in some parts of England as the first step towards converting the pasture to arable land; and it was thought that burning was essential to the success of such conversion in all cases where the old sod was known to be infested with grubs, wire-worms and the larvæ of insects. Instances are cited where comparative trials were made by ploughing one part of a field and sowing upon the inverted sod oats, which were utterly destroyed by grubs and wire-worms, while the other part of the field that was pared and burnt and sown with rape gave a superb crop. Not infrequently when old grass land was pared and burnt, so large an amount of ash was obtained that a part of it was carted away to other parts of the farm and used for manuring turnip fields.

Field Experiments on Burnt Soils.

From field experiments made in Germany by Struckmann, it appears that both "paring and burning," properly so called, and clay burning, but particularly the latter, have distinct merit. According to this observer, clay burning may undoubtedly be practised with advantage in many cases, even in localities where the cost of burning is high. In the first year of his experiments neither vetches (cut green) nor flax profited much from the burning, and it is evident that the burning of a soil can hardly be advantageous for vetches or for any other leguminous crop, since fire would be apt to clear the land pretty thoroughly of the symbiotic bacteria on which the success of such crops largely depends. But the crops of rutabagas and cabbages were largely increased, both on the plots that had been pared and burnt, and upon those that were dressed with burnt clay. After the crops had been gathered, and the land had been prepared for wheat, it was noticed that the mechanical condition of the soil was surprisingly good upon the burnt plots. Instead of the old heavy, stiff, cohesive clay, there was found a light, crumbly loam.

After the crops of the first year had been harvested, the land was laid down to winter wheat, so that in the second year wheat was grown upon all the plots, and it was found, not only that the effects of guano and lime applied in the previous year were specially conspicuous upon the burnt plots, and on those which had received a dressing of burnt clay, but that guano applied in the second year produced better crops upon the burnt land than upon that which had not been burnt.

In a series of experiments on turnips, Lawes applied the ashes of clay and weeds at the rate of fifteen bushels to the acre with excellent effect. The crop harvested compared favorably with those got by means of other manures, and was more than double that obtained from unfertilized land. The clayed field was fairly well stocked with plants, and the average weight of bulbs was nearly three quarters as large as in any of the twenty other experiments. Compare the experiments of Zacharia on burning moorland, cited on a subsequent page, as illustrating the idea of taking burnt soil from one field to put it upon others.

In one case reported by Pusey in England, an old grass field, on an extremely tenacious clay, having been drained and then pared in February, a part only of the sods could be burnt, because very wet weather interrupted the process. The whole field was sown with oats, and there was harvested from the land where the sods were burnt forty-eight bushels to the acre, while the unburnt land yielded only sixteen bushels to the acre. After the removal of the oats, the whole field was again pared, and a part of the sods were burnt, but wet weather interrupted the burning so that on a part of the field the sods had to be left lying in heaps. Wheat was sown, and gave a very good crop on the burnt land, and a poor crop on that which was not burnt. Forty bushels to the acre were got from the burnt land, and twenty from the unburnt. After the wheat, the whole field was pared yet again in August, and thoroughly burnt, together with the unburnt sods of the previous year. The yield of wheat was now 42.5 bushels to the acre upon the entire field. Manifestly, in the case of a clay like this, the mechanical improvement of the soil due to the dissemination of the non-plastic ashes must be of paramount importance. Occasionally it has been noticed that heavy applications of burnt clay sods have made the land much darker than it was before, and consequently warmer, so that wheat grown upon it was fit to cut some-

what earlier than that on the same field where none of the burnt earth had been applied.

Cartwright, experimenting on a cold, adhesive clay, applied 400 bushels of roasted clay to one portion of the land, 100 bushels of wood-ashes to another, and nothing to a third portion. He harvested the following crops, respectively, from the different plots: —

Plots treated with	Rutabagas. cwt.	Kohlrabi. cwt.	Potatoes. cwt.	Barley. Bushels.
Burnt clay	502	$137\frac{1}{2}$	480	36
Wood ashes.	472	$78\frac{1}{4}$	456	34
Nothing	204	$87\frac{1}{2}$	340	24

Mr. Cheer, as reported by Pusey, operating upon a field of extremely stiff, refractory clay, which had been considered to be of very bad quality before it was drained, applied burnt clay at the rate of 80 yards to the acre to two-thirds of the land, and folded sheep upon one of these thirds, while the remaining third received neither clay nor manure of any kind. Wheat was sown upon the land and a very fine crop was reaped. The yield of grain on the undressed land was 38 bushels to the acre, on the land to which burnt clay alone was applied it was 46 bushels, and on the land that got both burnt clay and sheepfold it was 48 bushels. The summer was wet, and the wheat lodged somewhat on the land where sheep had been folded, whence it appears that for this particular soil and season the burnt clay by itself was a sufficient manure, and that the fertility due to the dung was more than the crop could bear.

Mechi's Dicta.

Mr. Mechi, a London alderman, who not infrequently talked sound sense in spite of occasional vagaries, was strongly in favor of clay burning. He says: "Burned clay ashes are true friends of the farmer on heavy land. They descend gradually into the subsoil beneath the ploughed land, fertilizing it, and rendering it more porous and acceptable to the roots of plants. Twenty years of experience have taught me that nothing pays better than burning stiff brick-clays in dry weather. From a state poisonous to plants, the land passes, by burning, into a fruitful condition. Worthless pastures, ploughed lightly and burned, become fruitful and productive fields."

"How remarkable," he exclaims, "is the change produced in stiff clays by burning! Cold, wet, heavy and adhesive, or slippery, according to the weather, they at once become friable, non-

adhesive, warm and dry." And again, speaking of burned earth, he says: "Our stiff, plastic, non-calcareous clay, almost free from vegetable matter, becomes, when burned, real brick-dust, and yet it is a most valuable fertilizer. Twenty years ago I burned an immense quantity with great advantage. Science teaches us the why and the wherefore. It tells us that the hitherto unavailable elements of plant-food locked up in our stiff clays become liberated by the action of fire, and are rendered available for the feeding of our crops. But there is another and a more important advantage. The physical condition of the soil is entirely changed by burning. The bird-lime or putty-like soil, previously almost impervious to air or water, becomes loose and friable, permitting the free circulation of plant roots, and making the land work easier and leave the plough easily. There is no safer investment on stiff clays than burning the sticky, dense, unmanured subsoil. Where fuel is dear, the clay must be dried in the air before burning, and it is of course summer work anyway. One ton of soft-coal dust will burn twenty tons of earth."

In many instances, the duration of the beneficial effects of paring and burning are said to be very remarkable. Cases have been recorded where the improvement due to the burning was still conspicuous after the lapse of twenty years; the more particularly where one part of a field had been well burned and another part not so well, because of less favorable weather. Many farmers have argued that, apart from draining [and possibly steam ploughing], there is no process of agriculture by which so much good can be done to clay land as by skilfully burning it.

Coal-Ashes analogous to Burnt Clay.

It is to be noticed that much of what has been said of burnt clay will apply to coal-ashes also. Practically, coal-ashes have been found to do excellent service on clay soils. They are better than sand, because the latter does not mix readily with clay, but tends to run down to the bottoms of the furrows, channels or scratches which are made with ploughs, harrows and cultivators. Ashes on the contrary — whether obtained by burning coal or by burning clay — do not "flow" as sand does. Hence they may be mixed with clay and they will remain in the clay and will not sift out into the subsoil as sand is apt to do.

Refractoriness of Clay.

As has been stated repeatedly already, the chief trouble with

clay soils in their natural unregenerate condition is their plasticity and their dominative character. It is said that when a soil contains as much as 30 % of pure clay the character of that soil will be controlled by this constituent. Clays are commonly "strong" soils, in the sense that they contain a large proportion of plant-food, but they are at the same time "stiff" and "heavy," hard to work, little permeable to moisture, and slow to dry. A clay soil will absorb a great deal of moisture, and will retain it obstinately, and it is easily conceivable that both these qualities may be useful in favorable years. But in wet seasons, clay lands remain excessively wet, and any attempt to cultivate them while wet might be fatal, since the instruments of tillage would simply puddle the earth.

The risk that clays may "run to mud" when rained upon, so that both crops and land are smothered, has already been insisted upon, and so have the pernicious crusts which are formed when the mud becomes dry. In times of drought, clay lands are apt to be baked so hard at the surface that the roots of plants can hardly penetrate them; the land cracks withal, and in that way tears asunder and destroys many roots. So too, in winter, the wet clay "heaves" badly in freezing, and destroys plant-roots in that way. Hence the great advantage of draining, and of introducing the rough ashes and burnt clay just now under discussion as a means of altering the relations of the soil to water.

Burning of Long Stubble.

In some parts of Southern Europe where the dryness of late summer does not permit the land to be worked in the usual way between the time of the wheat harvest and that of sowing autumn grain, wheat may, nevertheless, be grown continuously by the device of burning the stubble and weeds upon the land and harrowing the roasted earth. The wheat is harvested with a header, as it were, i. e. it is reaped higher than usual, and the straw is burned where it stands. In this way, the condition of the surface soil is so much modified that it can be scarified and harrowed, even before the advent of the autumnal rains, and made mellow and friable to a sufficient depth for the reception of the seed-wheat. An incidental gain is found in the destruction of the eggs of insects and the seeds of weeds. (Gasparin.) It is not improbable that this method of procedure has come down from the ages of antiquity. It may well be older than the system of paring and burning just now described.

Burning of Moorland.

The burning of peat and moorland, that is to say, of soils surcharged with humus, is even more important as a means of culture than the operations already described, the chief significance of which depends upon the roasting of clay. Moor-burning is practised to an enormous extent in many places, particularly in Finland and in several of the Northern provinces of Germany, notably in Hannover, Friesland, Lunenburg, and Oldenburg, and in Holland also. In these regions it is still the usual method of reclaiming peaty soils, and very large tracts of moorland there have been brought into profitable cultivation by means of it. There are many localities, indeed, where no other known system of cultivation could be made profitable under the existing conditions as regards labor and roads. Moor-burning has the merit of being a quick method of putting waste land to profit. Thus, a German farmer, Lippe, has written as follows: —

"At the beginning of last year, three and twenty acres of waste peat-moor lay before me, where now is to be seen only a field of most luxuriant rye.

"The waste land produced nothing but rushes, wool-grass, and a few spears of sour forage, beside thistles and enormous masses of aquatic mosses. Here and there a miserable bush or a crippled birch was visible, but in most places the spongy soil sank under the feet of whatever trod upon it. Formerly cattle had been permitted to seek a meagre subsistence upon the tract, but they often sank deep into the miry ground, and could only be extricated from the seemingly bottomless slough by means of beams and levers, ropes and windlass, applied at the risk of one's life. But by simply draining and burning the waste land, without applying to it any manure or other ameliorant, it has been converted as if by magic to an exquisitely green field of most vigorous rye."

Moor-Burning not necessarily exhaustive.

In a case like the foregoing, and indeed as a general rule, one great merit of the burning consists in destroying the loose moss and other trash which encumbered the surface of the land.

The objection has been made sometimes, that large quantities of valuable peat must be destroyed on burning moorland, and the governments of some of the German states have been solicited to interfere in the matter, and prevent the waste of the national wealth. But in point of fact this objection is not very well founded. It is not ripe peat that is destroyed, — the farmer does not seek to destroy much of it, — but chiefly the crude superficial coating of moss and roots. In the German practice, the depth to

which this crust is burnt rarely exceeds some 12 or 16 inches, and it has been observed in districts where moor-burning has been practised for centuries, that the amount of material destroyed is hardly appreciable. For when the land is left to lie unused, mosses and other plants grow upon it, and after a while it becomes covered with vegetation and fit to be burnt again in due season. The real objection to moor-burning is the cloud of unpleasant smoke which fills the air. There are anti-smoke societies in several of the Northern German cities, which work to instruct, persuade, and coerce the farmers to desist from a practice which at certain seasons greatly annoys the citizens.

The methods employed for moor-burning vary somewhat in different localities, but, speaking in general terms, it may be said that the surface of the land is pared at a dry time to a depth which experience has shown to be sufficient; the sods are allowed to dry, being often set on edge to facilitate the drying, and are finally burnt, either as they lie, or in little heaps, without any special care being taken to regulate the rate of combustion. The ashes and carbonized matters are spread and harrowed in immediately. Care is always taken to burn the sods at a time when there is water enough in the soil to prevent the fire from penetrating to too great a depth.

In the best practice, as where the moor has been drained as a preliminary to the burning, the land once reclaimed in this way is kept in good condition by the use of manures, either natural or artificial, notably by means of guano, superphosphate, phosphatic slag, bone-meal, lime, and potash salts. Usually, however, the burnt land, after it has been cropped for a series of years, is left to lie fallow, and to revert to its original condition, while a new parcel of the wild moor is burnt and brought under cultivation.

Effects of Fire on Peat.

Several useful effects are brought about by burning peaty soils: the wild vegetation is destroyed, and its ashes, as well as those of the burnt peat, become available, both as manure properly so called, and as material for improving the mechanical texture of the peat that is left. Beside what is actually burned, a very considerable quantity of the peat is charred. That is to say, it suffers all conceivable degrees of alteration, from being slightly scorched, or even barely heated, up to being burnt to a cinder. But all the peat thus altered goes to change the texture of the soil,

and to improve its physical condition, especially as regards its power of absorbing and holding water.

Crude Bog-Earth is not Mellow.

It is a peculiarity of many unregenerate bog-earths that, on being ploughed, the furrows do not dry out kindly. Far from "slacking down" to the condition of mellow loam, crude bog-earth is apt to form on drying a multitude of very small and very light clods, which in the aggregate might well be described as constituting a light, incoherent, dark-colored, non-capillary gravel, not at all well fitted for the support of crops. When well drained, such soils may often change of themselves in the course of time to useful loams by mere process of decay and impaction; but as is well known to practical men, the improvement may be greatly hastened by the use of amendments, such as the carting on of gravel, especially limestone gravel, or, much more cheaply, by burning some part of the bog-earth, as has just been said, for the sake of ameliorating the remainder.

But, beside changing the texture of the peat, the heat distils off and destroys resinous matters which would cause the dry peat to repel water; and it destroys the acids which make the moorland sour. The burning acts also to promote the solubility of inorganic materials in the peat, just as it acts upon clay to that end, and numerous experiments have shown that the phosphoric acid in moor-earth is really much more accessible to plants after burning than it had been before. By means of muriatic acid, 20 % more of the total phosphoric acid can be dissolved out from the burned earth than can be dissolved from the unburned earth. Several of the facts above mentioned have been proved by Stoeckhardt, by a set of experiments in which a lignite-like moor-earth was gradually heated. Thus he found: —

In 100 Parts of the Earth	When Dried at 100° C.	When Roasted 8 Hours, at 200° C.	at 300° C.	After Distinct Glimmering.
Combustible matter	81.70	78.50	72.25	41.30
Ashes	18.30	21.50	27.75	58.70
Inorganic matter, soluble in water	0.47	0.84	0.53	2.58
Organic matter, soluble in water	1.36	1.25	0.43	0.99
Resin, etc., soluble in alcohol	3.55	2.52	1.10	0.87
Lime needed to neutralize the acid	3.75	2.14	0.27	0.17

But gradual and successive stages of heating, such as were here studied, would naturally be found in practice in the peat beneath

that actually burnt. Wild in his "Die Niederlände," speaking of moor-burning, says that in this system of husbandry it is not the intention to burn the sods to ashes, but only to change them to imperfect charcoal. Moor-burning is not a process of combustion properly so called, but a system of carbonizing turf that is thickly beset with heather.

To show how true this assertion is, Wild's description of the method of burning a primeval moor may be quoted. First of all, frequent drainage ditches are cut, and the moor is left to dry out somewhat, a process which often requires several years. The growth of heather and other plants on the surface of the moor is then pared off, usually in autumn, in great flaps, which are left lying inverted beside one another, exposed to wind and sun so that they may dry off during the winter. Next spring, as soon as the moor can be worked upon, usually at the beginning of May, the partially dried sods are set on fire on the under side where the heather is. They burn slowly, without visible flame, but with a very thick smoke, not to ashes, but merely to imperfect charcoal for the most part. It is customary to light the sods between seven and nine o'clock in the morning, when the dew has evaporated, and to extinguish the fire towards evening. Fire is set at the leeward edge of the field, in order that the combustion may proceed with regularity, and be kept under control. The laborers take pains to smother any places where actual flame may break out by throwing damp sods upon the fire. In the course of 48 hours after the burning, buckwheat is sown in the warm ashes, and harrowed in with hand-harrows.

The idea has occasionally been thrown out in England that it might often be well to burn peat to charcoal in special kilns and to apply this charcoal for fertilizing turnips and other roots. It is claimed that turnip seeds germinate very quickly when peat charcoal has been drilled in with them, and that the quick growth of the young plant enables them to escape the attacks of the turnip-fly. When thus drilled in with the seed from 30 to 40 bushels of the charcoal to the acre have been used, but sometimes the charcoal has been scattered broadcast by hand, or strewn with shovels at the rate of from 100 to 150 bushels to the acre. This subject is one worthy of scientific investigation, for the practical fact that the charcoal acts favorably upon turnips has not yet been adequately explained. It is not improbable that the charcoal may have considerable influence upon fermentations in the soil.

Experiments on Burnt Moors.

Some highly instructive field experiments have been made by Zacharia, in Germany, to test the questions: Is it the destruction of the undue excess of humus that improves a peaty soil when it is burned? or is it the alteration in the character of the soil as regards its power of absorbing water? or is it the ashes produced, that are specially beneficial? In other words, What is the relative value of each of these several factors, and how does their value compare with that of manures that might be bought and applied to the land? And how does the method of culture by burning compare with other methods of culture?

Three parcels of moorland were staked out and treated as follows. The sod of the first parcel was ploughed under in the autumn; that upon the second parcel was pared and carried away from the land in the autumn also; but the next spring the sod upon the the third parcel was pared and burnt in heaps upon the land. Each of the parcels was then subdivided into plots, and the plots upon the burnt land were treated as follows. From plot "A" the ashes were carefully collected (there were some 9,000 or 10,000 English pounds of them to the acre), and transferred to Plot "C," where they were strewn, together with the ashes proper to "C." But the ashes of Plot "B" were strewn upon that plot. Various manures were applied to the plots of the other parcels of land, and the whole field was finally ploughed and planted with barley, in May. At the middle of August the barley was harvested with the following results in Prussian pounds to the Morgen:—

Plots.	Parcel I. (Sod ploughed under.)		Parcel II. (Sod carried off.)	
	Grain.	Straw, &c.	Grain.	Straw, &c.
(a) No manure	58	165	14	75
(b) 1,000 lb. wood-ashes .	198	375	196	321
(c) 200 lb. bone-meal . .	219	450	122	334
(d) 100 lb. Peru guano . .	111	439	135	394
(e) 1,000 lb. lime	41	184	35	120
(f) Sand	97	286	31	65

Plots.	Parcel III. (Pared and burnt.)	
	Grain.	Straw, &c.
A. No ashes	373	828
B. Its own ashes	850	1,300
C. Double dose ashes	847	1,552

It appears, 1, that it was better to plough under the sod than to

carry it off; 2, that the lime was of no use as regards this first crop; 3, that although the bone-meal and guano and ashes were useful, they were not very useful, — neither of them gave any money profit; 4, that the mere heating of a portion of the soil by the process of burning the sod in heaps, even when the ashes were removed, did twice as much good as the average action of the guano and wood-ashes and bone-meal; 5, that this heating of the earth plus the ashes resulting from the paring and burning gave abundant and profitable crops, while the double dose of ashes did little or no good.

It was made plain by these experiments that moor-burning was an eminently proper mode of culture for the land upon which the trials were made. It was proved also that the heating of the earth was as important as the production of ashes; indeed, it was of more importance, for the moment the amount of ashes put upon the land was in excess of what the crop needed, it was evident that matters had been carried too far. For the case in hand, the paring of a thin slice of sod would have been better than a thick slice.

Thin Moors not fit for burning.

It is not to be supposed that all moors should be treated with fire. No small amount of evidence has been collected in France, which goes to show that, in that country, the good effects of moor-burning, though plainly manifested at first, are ephemeral, and not to be seen after one or two seasons. The chemist Malaguti, who lectured at Rennes, in the West of France, has much to say about the system as practised in his vicinity. He shows clearly that, under the conditions which obtain in that locality, the merit of the process depends, not upon chemical considerations, but upon its cheapness, and upon the fact that it yields a quick return for the labor expended.

It would appear, however, that the French moorlands are very different from the German. The French moors do not consist of deep beds of organic matter, but are thin, cold, sour, shallow soils, overlying sand or gravel, sparingly beset with worthless grass or bushes. Hence the burning of a French moor would seem to be more nearly akin to clay-burning, or to the paring and burning of old grass-sod, which is probably seldom or never justifiable unless it be connected with a system of turnip-growing and sheep-raising upon stiff clay land.

For the permanent improvement of this kind of moorland, — unless indeed it is based upon clay, — it has been found to be best to turn under the sod and let it rot in the ground, rather than to destroy the nitrogen in the organic matter by means of fire.

Brush-Burning.

The burning of logs and brush, when new land is cleared, has evidently, so far as the chemistry of the subject is concerned, much in common with the processes of clay-burning and peat-burning. Brush burning is practised in all wild, wooded countries. It is almost as common to-day in the Scandinavian countries, and in some districts in the interior of Europe, as it is in the Northern United States.

German writers very often give brush-burning a place in their lists of the different systems of farming. Indeed, one could hardly find a more concise account of the practice than the following, taken from an account of the agriculture of Bohemia, printed in 1856:

"The brush-burning system of farming, the so-called clearing of land by fire, which consists of a rotation or interchange between woodland and tillage, is practised to a certain extent in the mountainous parts of the country, as well as in some of the more densely wooded sections. It consists in cutting down the wood or the bushes from the tract to be cleared, and burning them upon the land. The ashes are then scattered, the earth broken up, as well as may be, and seeded down once or twice with oats or rye. The ground is then left to cover itself with grass, and finally with bushes and trees."

There are, of course, a variety of intermediate systems between this crude process described by the Bohemian writer, and the methods of clearing in which no fire is permitted. Some of our farmers, for example, sow grass-seed with the rye, and often, of course, the land is kept permanently under cultivation instead of being allowed to revert to the condition of forest. But, so far as concerns the chemistry of the matter, these points of detail are wholly immaterial. For the moment, the question at issue is, What effects may such fires have upon the land? Something may be learned as to this point by considering what happens in the cases of clay-burning and moor-burning as already considered.

In brush-burning more or less of the humus which had accumulated while the land was in wood is liable to be destroyed at the spots where heaps of logs or brushwood are burnt, and in nine

cases out of ten this result may be accounted highly pernicious. It is precisely this woodland humus that is usually the sweetest, the mellowest, and the best. The fire will naturally destroy much of the nitrogenous matter which has been accumulated by the symbiotic fungi, which live on the roots of trees, and it may kill many useful micro-organisms which were living in the soil. Of course, there is an abundant production of ashes, which contain a great store of plant-food, which has gradually been brought up from the subsoil by the trees and bushes during the entire period of their growth, and it is true enough that, by means of this supply of plant-food, the crops of the first and second years are usually well manured, though a good part of the ashes are sometimes swept away bodily from burned land by heavy showers, while some of them are apt to be blown away by wind. When the soil to be cleared contains clay, some of the good effects of clay-burning are doubtless produced, and in most instances many rocks and stones are crumbled.

Looking at the matter solely from the chemical point of view, it is hard to escape the conviction that brush-burning commonly injures the land, and that those methods of farming are preferable which work to prevent the growth of bushes upon land that has once been cleared. When trees or bushes are actually present in places where wood is not merchantable, the process of burning is as a matter of course, amply justified by the mere mechanical necessity of removing the wood from the land. It is to be remembered that, if wood were not combustible, it would be as much in the way upon the land as so many stones of equal magnitude. But for situations where other methods of culture are economically possible, it may be urged as probably true that no ephemeral advantage gained from the ash manuring, or perchance from the roasting of clay in the soil, can compensate for the destruction of the nitrogen in the humus which had accumulated beneath the bushes or trees.

CHAPTER XXXII.

IRRIGATION.*

If it can be said of any one item of good practice in agriculture more than of another, that it is shamefully neglected in the

* It will be noticed that this chapter has been written from the point of view of a New Englander. It relates more particularly to non-arid regions, where irrigation may be em-

Atlantic States, it will assuredly be said of irrigation. In spite of all that has been done of late years in California and the adjacent regions, it is still probably true that no other subject relating to agriculture so much needs to be attended to by the American people as this matter of watering the land.

Strange as it may seem at first sight, the question of irrigation is largely a chemical question; and in asserting that the densest ignorance seems to prevail among New England farmers with regard to this branch of husbandry, it is not meant to imply that the people of this section of the country know nothing about the guiding or lifting of water by means of aqueducts and sluices, or by windmills or steam-pumps. On the contrary, the history of milling and manufacturing in New England, and of hydraulic mining in California, teaches that there are few people more ready to undertake the management of water than our own, or better able to deal with it.

Water may act as Manure.

It is urged only that comparatively few of our farmers seem to have any just conception of the fact that, by applying water to the land, we manure the land by means of matters which the water holds dissolved and invisible. Not only may land be fertilized in this way, but in many cases it may be fertilized adequately for the continual production of remunerative crops. Indeed, it may be said of almost every case where land is skilfully irrigated, that fairly good crops of hay, at least, may be obtained year after year without adding any other manure than that which the water affords; meanwhile, the artificial supply of water does away with the risk of drought, and permits the farmer to grow with success such crops as he may please, even in situations which might otherwise be quite unfit for those crops.

Some of the experiments made in recent years by the methods of water-culture and sand-culture teach an important lesson as to the true significance of irrigation. It is easy, for example, to grow tolerably good plants in mere pit-sand which is abundantly watered with brook or river water. Indeed, Boussingault reports

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ployed as an auxiliary, although it can hardly be regarded as a necessity. Anyone interested in studying the great irrigation enterprises of California and the neighboring states will naturally consult the numerous reports of the Geological and Agricultural Departments of the United States Government, and the special books and treatises on American irrigation which have recently been published. Many excellent articles on Western irrigation will be found, also, in the popular monthly magazines of this country.

that he has seen rich crops of Indian corn harvested upon the plateau of the Andes on sand that was almost moving, but which was abundantly and skilfully irrigated. It may, in fact, be accepted as a general truth that plants can get all the food they need from almost any soil that is properly watered, and kept warm enough. The familiar fact so often to be observed in domestic horticulture, that cuttings of various plants will grow and even thrive in jars of well-water, goes far to enforce a similar lesson. But there is small need to multiply instances to illustrate a subject which has already been dwelt upon at sufficient length in another chapter.

If, as has been shown, plants take in their food from and through the soil-water, it will evidently be good policy to supply water enough to enable them to take up their food to the best possible advantage, under the most favorable conditions. If, as has been shown, large quantities of nitrates and of other useful ingredients run to waste in the waters of brooks and rivers, it will manifestly be well to pour such water back upon the land from which it has soaked out, or, better still, to pour it upon land that stands in special need of nitrates and the other dissolved matters.

Moreover, if it be true, as is seen indeed to be the case every summer in times of plentiful rains, that an abundant and well-distributed supply of water is most favorable for the growth of plants, there can be no question that many farmers here in New England would do well to provide a permanent and controllable water-supply when they are so situated that they can do so without undue expenditure. I have myself grown several kinds of plants, with success, in coal-ashes admixed with peat, and freely watered. Of course manure may be put upon land that is to be irrigated, as well as upon any other.

Moisture enables Manures to act.

It is possible, especially in warm climates, to obtain surprisingly rapid successions of crops by manuring land heavily and frequently, and watering it freely; and it must often be true of these cases that fertilizing matters are applied in such large quantities that the influence exerted by them will wholly overpower that of the natural fertility of the soil and that of the plant-food which was originally contained in the water. Gasparin has dwelt upon this idea when writing of irrigation at the south of France; and in a similar spirit it has been urged by Caird of certain localities in

India (as at Cawnpore), that on highly manured land near a great city the value of water used for irrigation is immensely greater than when applied to poor, unmanured land far from a market. It is precisely upon well-watered soils that manure is used with the utmost advantage, since under these conditions the crops can readily gain access to and absorb the fertilizing matters. In many situations a small amount of manure applied to irrigated land will produce results such as could not be obtained by the most generous dressings of dung, if the land had nothing to depend upon but the rain which falls upon it.

Every New England farmer knows that it is in rainy years, and not in years that are dry, that his poor, light soils produce tolerable, or even good crops, and it is precisely upon such soils that abundant crops could be obtained every year by systematic irrigation. It is true enough, as a general rule, that crops suffer less from drought on well-manured land than on land that has been inadequately fertilized; but it is true also, that a small amount of manure upon land abundantly moistened will do far more good than a much larger quantity of manure could do without the moisture.

Many farmers in New England have noticed that upland pastures and mowing-fields so situated that the "wash" from a road can flow upon them in times of rain, often derive no little benefit from the water. The case is really one of intermittent irrigation, whereby the store of water in the soil of the field is occasionally replenished. Ordinarily no great amount of actual plant-food can thus be brought to the land, and, in any event, much worthless sand and gravel are apt to come with it, though it must be admitted that the colloid clay from the muddy road may sometimes serve to improve a field of hungry sand or gravel; and it may happen also, occasionally, that spores of the symbiotic bacterium, which grows on clover-roots, are present in the wash.

Light, porous soils, that are not too fine, and particularly gravels and sands, are specially proper for irrigation, for the excess of water can readily drain away from them, and there will be comparatively little risk of puddling such soils at the surface. Clays, on the contrary, are not well adapted for the process, and probably can seldom or never be benefited by it, unless they are provided with tile-drains and kept permanently in grass, or are very

carefully mulched. According to Hilgard, it is found to be difficult, in California, to irrigate those soils which contain a large proportion of fine silt. Into such soils water penetrates so slowly that the ditches must be placed no more than a few feet apart, and the flow of water has to be continued for a considerable length of time in order to wet the land.

Importance of Water as such.

Water considered merely as water, without reference to the plant-food which is dissolved in it, is an important agent in promoting the growth of plants. As Boussingault has suggested, it might well be said that the cells of which plants are composed really live their lives in the midst of water. Not only the circulation of matters within the plant, and the chemical processes and reactions which occur there, but the very life of the plant, depend upon the presence of an abundance of liquid water. When water is plenty, many plants can use over and over again a given store of ash-ingredients. That is to say, even a small store of ash-ingredients, such as might be present in a seed, can be used first in the young shoot, and then in the future leaves, and yet again in the leaves that follow, provided the plant be kept juicy by means of water. This fact is seen often enough in the case of Wandering-Jew plants kept in water, and it may readily be exhibited by sowing nasturtium seeds in pure sand and watering the young plants with rain-water. Several successions of leaves on a long, straggling plant can readily be obtained in this way.

The significance of water, considered only as water, is specially well marked in arid countries, not only because very little water is there supplied naturally to the crops, but because, from the very fact of the aridity, the soils of these countries are usually highly charged with plant-food. The conditions under which these soils have been formed have led to their containing an unusually large proportion of the hydrous double silicates which serve to fix and hold potash and other bases, and they have never been subjected to any such leaching action as that which tends constantly to impoverish the soil in regions of abundant rains. In these facts may be found an explanation of the enduring fertility, and the capacity to sustain dense populations, which have been exhibited by several of the irrigated countries of the old world. (Hilgard.)

"Rain-crops."

As has been set forth in Chapter IV, in respect to the growing

of grain in California, the power of certain crops to come to maturity by virtue of moisture held in the soil for a time after the scanty rainfall of the winter, has led in some arid localities to the designating of such spring-grown crops as "rain-crops," in contradistinction to crops obtained by way of irrigation, which in those regions is the chief resource. In some places, the winter's snow may be of no little importance in this sense, because it supplies moisture gradually, on melting, for the support of spring crops. Thus Capt. Yate, in describing the valley of the River Murghab, in Afghanistan, has said: "The snow, as it lies and melts, seems to act like a hot-house to the vegetation below it. These rain-lands only produce one crop every year. Much of their fertility, it would seem, is caused by the snow, which, unlike rain which falls and flows away, lies and melts slowly, at once fertilizing the soil, and turning it, with its warm covering, into a veritable hot-bed."

Quantity of Water needed by Plants.

The fact has been mentioned already (page 136 of Volume I) that field-crops require enormous quantities of water in order that they may grow freely. But it may be well to insist again upon this point. To begin with, most plants contain a great deal of water as a normal constituent. Analysis shows as much as 95 lb. of water in every 100 lb. of the more succulent fruits and vegetables, such as melons, cucumbers, lettuce and asparagus, and some 90 % in ordinary roots and vegetables; young grass contains 80 to 85 %, grain-plants when in blossom 75 %, and even mature leaves of trees some 60 %. Since these proportions of water are found to remain wellnigh constantly the same in healthy plants, even when the external conditions vary considerably, it seems plain that they cannot be accidental, but that they must be essential for the physiological processes which occur within the plant.

It is easy to see why plants should contain a great deal of water, because nothing can be more evident than that the contents of their cells need to be kept moist. The protoplasm of the active cells has to be kept in a glutinous, half-liquid condition, in order that its functions may be properly performed. In case the contents of the cells should become too consistent through loss of water, the activity of the cells would be diminished, and would wholly cease if all the water were removed. In order to the continuous life and growth of a plant, there must be continual move-

ments of matter within it from one cell to another, and from one part of the plant to another, such as could not occur unless the active cells and membranes were kept constantly moist. In general it may be said that a plant can grow freely only when it is properly charged with moisture. Whenever, from any cause, the supply of water is inadequate, the development of the plant must necessarily be diminished.

Even the decomposition of carbonic acid by the leaves of plants cannot proceed normally unless the leaves are well charged with moisture. Plants standing wilted in a field are to be regarded as crippled and idle, in so far as the production of carbonaceous matter is concerned. In his experiments on cherry-laurel leaves, Boussingault obtained the results given in the table: —

Condition of the leaves.	Water in the leaf. Per cent.	Cubic centimetres of carbonic acid decomposed in 7 hours by 34 square centimetres of leaf.	Cubic centimetres of carbonic acid decomposed in 1 hour by 1 square centimetre of leaf.
Normal leaf . . .	70	16.9	0.071
Somewhat dried .	36	10.8	0.045
Much dried . . .	29	2.9	0.012
Completely dried .	00	0.0	0.000

He found that leaves which had been thoroughly air-dried had no power of decomposing carbonic acid on being moistened. In a word, the leaves were killed by the drying.

As will be explained more fully under the heads of Barley and Oats, most crops grow best on soils which are thoroughly well moistened, though not soaking wet. In order to yield perfect crops, a soil should contain all the time at the least from five to six tenths as much water as it is capable of holding. This point is illustrated by Birner's experiments on potatoes, as given in the following table: —

When the soil contained		Each potato-vine produced		
Per cent of water.	Water amounting to per cent of all it could hold.	Tubers. Grm.	Dry matter of tubers. Grm.	Comparative wt. of the crops.
24–32	60–80	809	202	20
16–24	40–60	628	153	15
12–16	30–40	413	88	10
8–12	20–30	313	65	8
4–8	10–20	214	44	5

When do Plants wilt?

As has been set forth on a previous page, the necessary supply of water comes from the soil, and is kept up by the osmotic pumping action of the roots, while, on the other hand, water is continu-

ally expended by exhalation of vapor from the leaves, sometimes in such quantities that a very few hours of hot, dry summer weather would be sufficient to dry out a plant completely if new supplies of moisture were not constantly brought into it to make good the loss. Numerous experiments have shown that, during the term of a healthy plant's life, rather more than 300 lb. of water pass through the plant for each and every pound weight of dry substance permanently gained from the soil and from the air.

It is in young plants at the time when leaves are being most freely developed that the need of water and the waste of water are greatest. An extremely interesting illustration of this point is afforded by the grain-crop of California. In that region, rain enough falls in the winter to supply the plants adequately with moisture during the period of active growth, but by the time of ripening there is no longer water enough left in the soil to enable a growing crop to prosper.

Hellriegel has made numerous experiments to determine, as nearly as might be, how small a quantity of water in the soil is sufficient to keep crops from wilting under ordinary conditions of temperature. Some of his results, as obtained with garden-loam, on different days in June, are given in the following table: —

When the Fahr. Temperature at Noon was about		When the Percentage of Water in the Soil was
80°	Lupines began to wilt	13
79°	Lupines did not wilt	14–16
76–82°	Beans began to wilt	10–13
79°	Beans did not wilt	14–15
76°	Clover began to wilt	14
70–80°	Clover did not wilt	13–16
76–80°	Buckwheat began to wilt	10–16
79°	Buckwheat did not wilt	14–16
76–81°	Peas began to wilt	7–13
76–81°	Peas did not wilt	8–14
80°	Barley began to wilt	8½
76–79°	Barley did not wilt	11–15

It appeared that plants differ considerably as to their powers of meeting an exceptionally rapid loss of water by transpiration. Peas and barley, for example, did better in this respect than the other leguminous plants, or than buckwheat. It was evident, as regards the plants examined, that, in order to guard against the possibility of wilting, there needed to be a tolerably large amount

of moisture in the soil. For the garden loam of the experiments, it may be said that at least 16% of water (about 35% of all the water this earth could hold) would need to be present in hot, dry summer weather in order to properly satisfy the plants. At more moderate temperatures, however, and in air less dry, plants might not suffer much inconvenience even if there were a considerably smaller quantity of moisture in the soil than this; and when the weather is cool and the air very damp, there need hardly be much more water in the soil than what would be held there hygroscopically.

Wilting is highly Objectionable.

Hellriegel insists that the wilting of a plant does not indicate its first actual sufferings from want of water, but is rather a sign of the beginning of the last stage of endurance. He urges that, whenever a soil has dried out to such an extent that plants can no longer quickly supply themselves from it with water to make good what they have lost by transpiration, the flow of sap within the plants must necessarily become sluggish, and all the movements of food or other constituents from one part of the plant to another must go on more and more slowly and incompletely, until they finally come to a standstill. So long as the drought continues, the proportion of water in the plants will diminish from day to day and from hour to hour, and the efficiency of the organs which move the sap will be more and more impaired, until outward signs of the trouble are manifested by the flabbiness of the leaves; but by this time the plant may have got into a condition most unfavorable for growth, and highly undesirable from the economic point of view.

Hellriegel has constantly observed on the sandy soil of his vicinity (Dahme in Prussia), that whenever a series of warm, rainless days, accompanied with drying winds, occurs in May or June, the vegetation of crops comes almost to a standstill. The development of young clover, for example, ceases well-nigh completely. But it is only after a long while that the clover begins to wilt, and at first the wilting is only visible in patches where the fields happen to be stony. But when wilting has once begun, only a few more days of hot, dry weather are needed in order to bring the entire field into this condition, and indeed to burn off and destroy the crop.

Once he took occasion of a sunny forenoon to collect and an-

alyze some of the wilted clover-plants at the first moment when wilting was shown by some patches of the plants. He found in the wilted leaves 71% water and 29% dry substance; in the stalks, 78.4% water and 21.6% dry substance; while in adjacent plants that had not yet wilted, he found in the leaves 82.5% water and 17.5% dry substance; in the stalks, 90% water and 10% dry substance.

Since the wilted plants contained nearly twice as much dry substance as the others, it is evident that the latter must have lost a great deal of water before their sufferings were made manifest by the wilting, and the inference is, that long before these plants wilted they must have been living under abnormal conditions. It is to be noted withal, that in case it had happened to rain freely the day before Hellriegel collected his specimens, no wilting would have been seen, although the crop had undoubtedly already, and for some time previously, been seriously crippled by the drought. In general, it may be said that the wilting of a crop affords no evidence whatsoever that the plants had previously been properly supplied with water. I am informed by Mr. Wm. D. Philbrick, of Newton, Mass., who has long been accustomed to grow early cucumbers under glass, that the vines exhale enormous quantities of water, and that, in case the leaves are allowed to wilt, many crooked and unmerchantable cucumbers will be harvested.

This matter has been summed up by Gasparin somewhat as follows: When water is lacking, and the plant can no longer exhale it, the sun's heat accumulates in the tissues to such an extent that in clear weather the temperature of the plant may rise 30° or 40° higher than that of the surrounding air, and the tissues will speedily dry out. But long before complete dryness the life of the plant will have been destroyed utterly. Thus it is that, while a plant adequately supplied with water may only prosper the more at temperature as high as 110° or 120°, it would soon perish in such heat if the supply of moisture were cut off. A discussion of the highly important question as to the amount of water needed by crops will be found in a subsequent chapter.

Quantity of Rain that falls.

In New England very large quantities of water come to the land in the form of rain and snow. Inasmuch as one inch of rain delivers 0.623 U. S. gallon of water to the square foot, 5.610 gallons to the square yard, or 27,154 gallons to the acre (i. e. 862 barrels,

or rather more than 113 short tons to the acre),* a rainfall of 40 inches, or even of 20 or 30 inches per annum, must supply an enormous amount of water to every acre of land. The chief trouble is the unequal distribution of the rain-water. In many regions, the land is drowned and baked by turns.

Amount of Water used in Irrigating.

Very large quantities of water are applied by irrigators, as a general rule, and in some countries enormous quantities have to be applied at first in order to fill up the land. Thus, in the extreme south of the San Joaquin valley of California, the annual rainfall rarely moistens the soil to a greater depth than 2 or 3 feet, and on digging or boring wells in non-irrigated districts the earth is found to be as dry as dust to a depth of 40 feet or more. On beginning to irrigate such land the entire mass of dry earth has to be moistened before moisture will remain permanently within reach of the tap-roots of plants, and a very large quantity of water is consequently required at first; but gradually the ground fills up and the water-table rises, as well as the plane of the capillary moisture, and the effect of the irrigation may be perceptible at a distance of many miles in the porous soils of the plains. Ultimately the amount of water annually needed for irrigation becomes several times less than was required during the first years. (Hilgard.)

Even in non-arid regions, very large quantities of water are thrown upon grass-fields in those countries where irrigation is habitually practised. In Italy, as Baird Smith concludes from the observations of several different engineers, an amount of water that would form a layer or stratum about 4 inches deep over the entire surface of the field, if it were possible so to spread it, may be regarded as sufficient to give a meadow a proper drenching. It is assumed in this case that about half the water will soak into the soil, while the other half flows off and is available for use upon lower-lying fields.

It may be said, in general, that there is no use in trying to irrigate land unless a copious supply of water is available. Economically speaking, mere sprinklings of water put upon land in times of drought do no good. In the immediate vicinity of Boston, it

* There are 4,840 square yards, or 43,560 square feet, or 6,272,640 square inches in an acre. One cubic inch of water weighs 252.458 troy grains. The U. S. gallon has a capacity of 58,372.2 troy grains of water, and contains very nearly 231 cubic inches of water. One avoirdupois pound is equal to 7,000 troy grains. A barrel is equal to 31.5 gallons, wine measure.

has been estimated that, during the warm, growing months,—May to September,—most vegetation would profit from an inch in depth of water over the entire surface of the land every five days on the average. Sometimes, in showery weather, less than half this quantity of water might be sufficient, while at other times more would be required. (Philbrick.)

It has been urged also for this locality that a quantity of water equal to a depth of about 2 inches, over the entire surface of an acre, i. e., nearly 50,000 gallons, will be required in order to properly saturate the soil.

Modes of estimating the Quantity of Water used.

A familiar unit of measure for irrigation-water is the rate of one cubic foot per second. The water is delivered through inlets of such height and breadth, and under such a head of pressure, that the number of cubic feet per second can readily be calculated by means of formulas which have been devised by the hydraulic engineers.

According to an experiment of De Regi, the continued discharge of 1 c. ft. of water per second is sufficient for the irrigation in 24 hours of 4 acres of mowing-field. The total amount of water discharged will be 86,400 c. ft.; and as the area watered is 174,240 sq. ft., it appears that there is water enough to form a layer nearly 6 inches deep over the surface of the meadow. In some parts of Italy, twelve such waterings are given in the season, at intervals of a fortnight. The above estimate implies, however, that the whole of the water is absorbed by the soil, which is never the case in actual practice. Lombard engineers calculate that from $\frac{1}{4}$ to $\frac{1}{3}$ of the water applied is absorbed by the soil. Naturally enough, there is great diversity of opinion even in Italy, with regard to the quantity of water that should be given to meadow-land; and on some of the English water-meadows, quantities of water even larger than the foregoing are said to be expended.

There are three ways in which the total quantity of water employed is estimated: 1st, by the volume of water in continued discharge required to irrigate a given area of land; 2d, by the total depth of water spread over the soil, either at each watering, or during the whole season of irrigation; and 3d, by the total cubic contents of the mass of water employed. Smith says that the statistics of irrigation in India show that the continued discharge of one cubic foot of water per second is sufficient for the

irrigation throughout the year of nearly 180 acres of land. Here the climate permits the use of the water the whole year through. In this estimate all kinds of cultivation are included, though it is well known that the consumption of water for different crops is extremely variable. Rice, sugar-cane, cotton, cereals, etc., each require their own special quantity of water.

It is said that the experience of practical men in Southern California shows that a flow of 1 cubic foot per second will irrigate 100 acres of land, and that this standard has been adopted in Utah also, while in Colorado, 55 acres per second-foot has sometimes been accepted as a basis of water-rights. Under special conditions, water may be made to supply comparatively large areas, as in some parts of California, where it is carried to the land in wooden flumes and allowed to run out from holes in their sides, or where in some orchards each tree is supplied from a separate outlet-pipe. By operating in this way, as much as 1,000 acres have been irrigated per second-foot.

On summing up the results of French and Italian experience, Buffon concluded that the irrigation of an acre of meadow requires under average circumstances the continued discharge of 18.5 cubic inches of water, which gives an effective power per cubic foot per second of 93 acres. Smith believes this to be a very close approximation to the truth, and he gives the following summary in support of it: —

De Regi's estimate	96	acres	per cubic	foot	per second.
Milanese "	78	"	"	"	"
Veronese and Mantuan estimates	68	"	"	"	"
Tadini's estimate	96	"	"	"	"
Buffon's "	93	"	"	"	"

The reason why this estimate amounts to but little more than half the Indian, is that in Italy the water is seldom used during more than half the year. The great mass of the water consumed in Italy is used between the middle of March and the beginning of September.

For Germany, Koenig has estimated that there is required on an average, for ordinary superficial irrigation, 100 litres of water per hectare and per second.

"In Southern California, the standard of measurement of water is the miner's inch under 4 inches pressure, or the amount that will flow through an inch-square opening under a pressure of 4 inches measured from the surface of the water in the conduit to

the centre of the opening through which it flows. This is 9 gallons a minute, or, as it is figured, 1728 cubic feet, or 12,960 gallons in 24 hours, and one-fiftieth of a cubic foot a second. This flow would cover 10 acres about 18 inches deep in a year; that is, it would give the land the equivalent of 18 inches of rain, distributed exactly when and where it was needed, none being wasted, and more serviceable than 50 inches of rainfall as it generally comes. This amount, with the natural rainfall, is sufficient (in Southern California) for citrus fruits and for Indian corn and alfalfa, in soil not too sandy, and it is too much for grapes and all deciduous fruits." (C. D. Warner).

Irrigation water as compared with Rain.

In countries where rain seldom falls, it may be accounted as one advantage in favor of irrigation that the water, when properly applied, does not act to beat down either the soil or the crops. But on the other hand, the pains taken by gardeners to sprinkle many kinds of plants points to the conclusion that the washing of leaves by rain must sometimes be advantageous. It is evident that falling showers will naturally wash away from the plant much dust which has adhered to it, which could hardly fail to clog the plant-cells and choke the breathing-pores, and they would remove exudations, also, which might otherwise encrust the leaves.

Kinds of soils fit for Irrigation.

In Europe, it is held that loamy soils are, generally speaking, well adapted for irrigation; they can bear neglect better than other soils. Calcareous soils are said to require much water, and to put it to good use. Naturally enough, less water will have to be expended upon soils of a certain degree of tenacity than on those which are extremely permeable. Thus it is said that in Italy and at the South of France, it will be proper to wet the land thoroughly once a fortnight in case it contains no more than 20 % of sand, once in every 11 days if it contains 40 % of sand, once in every 6 days if the sand amounts to 60 %, and every third day if there is as much as 80 % of sand.

As a matter of course, the quantity of water needed to maintain a soil in fit condition must necessarily vary with the climate, the character of the soil, the season and the crop. Even clays can be irrigated by exercising considerable care. They should neither be watered constantly, lest they become hard and cold, nor infrequently lest the land should crack on drying and tear the roots

of the crop. Perhaps the best help for irrigating a clayey soil would be to keep the land covered with a mulch and to apply but little water. Peat and moor-land, even when thoroughly drained, are held to be ill-adapted for irrigation. As a general rule, such land stands in comparatively little need of having water brought to it artificially; though, as will be shown directly, a peaty soil may often be greatly improved and consolidated by allowing muddy water to stand and settle upon it.

Water Meadows.

It was customary at one time long ago in Europe to arrange farms in such wise that each farm was based upon the occasional irrigation of one portion of it; and many such farms are still maintained there upon the Continent. The idea was, that, by means of a just proportion of permanent grass-land kept constantly productive by irrigating it, so many cattle may be maintained that the rest of the farm can be manured with the dung of these cattle. Those parts of the farm which are not devoted to grass are thus made to produce crops of grain, or other merchantable products, at the expense of the watered meadow. This method of procedure is a very old one, and it was most commonly put in practice when the European countries were comparatively speaking new and poor, much as New England is now. Doubtless there are hundreds of farms in New England that could be kept up, somewhat in this way, at trifling cost, in places where the fields are now seen to be burnt to a crisp in the August droughts, and comparatively sterile throughout the year.

Almost everywhere in New England there are to be found light, leachy, hungry soils, based upon sand or gravel, which become dry at the surface in a few hours after rains, and dry up completely in times of drought, often to the depth of many feet. Such soils are so easily worked, and are ready for the plough so early in the season, that they attract many farmers, especially those who are weak as to teams and laborers; hence they are very often cultivated. One point to be made in favor of these drift-gravel loams is, that they have a wide range of workability, so to speak; that is to say, they may be ploughed and tilled at almost any time, excepting when they are soaking wet, or perhaps when they are baked dry. It is not so with clayey soils which remain cloddy when ploughed dry, and work like putty when ploughed wet; and so, too, of some fine silts, or silt-like loams. Such

soils as these last have to be ploughed when "just right," or a risk is run of injuring their tilth for years.

When well manured, the light New England loams just now spoken of give good crops in wet seasons, though in dry summers they often yield nothing or next to nothing. When left as pasture, the worthless oat-grass or "white-top" (Danthonia) tends to supplant all useful forage. But such lands, if irrigated, would every year yield good crops, and they could readily be kept up as permanent pastures.

It seems hardly consonant with the fitness of things, when half-starved cattle are seen searching a brown hillside, in times of drought, for some scanty blades of grass, when ample supplies of water are close at hand that might readily be applied to make the hillside fertile.

It is not alone ponds, and water-holes, and low-lying brooks, that are neglected among us; there are multitudes of active brooks in the hill country, the waters of which need only to be diverted, and regulated as to their rate of flow. It would be easy to form, in this way, fields which would produce a crop of hay in June, and afterwards furnish abundant pasturage throughout the summer. Gasparin admits for the climate of Southern France, that well-manured grass fields will usually give when watered, three times as large a crop as can be got without irrigation.

In the long summers of Italy, permanent irrigated meadows are mown thrice, and occasionally even four times, in the season, and they are subsequently pastured in the autumn. Baird Smith has calculated the annual production from an English acre of such meadow as follows: —

Hay from 1st cutting	2,730 lb.
Hay from 2d "	2,072 "
Hay from 3d "	1,557 "
Total hay per acre	6,359 "

i. e. rather more than three tons of hay, beside the pasturage, which is reckoned to be worth about $2 the acre. It is said that in general the permanent meadows prevail only in localities devoted to the rearing of cattle, or in situations not well adapted for mixed cultivation, and that it is a common plan in Italy to have irrigated grass-fields alternate with other crops in regular rotations.

Gasparin mentions the following rotations as practised on

irrigated and manured land in Northern Italy: 1. Flax or millet. 2. Maize. 3. Wheat. 4. Meadow; or 1. Wheat and clover. 2. Clover. 3 Flax and millet. 4. Maize. 5. Meadow; and remarks that they were practised there in the 16th century. One plan cited by Burger is: 1. Flax. 2. Wheat, followed by millet, as a stolen crop. 3. Wheat, followed by maize as a stolen crop. 4, 5 and 6. Meadow. Baird Smith cites another example, as follows: 1. Wheat, to be reaped in July, grass-seed being sown with the wheat. 2, 3 and 4. Meadow under irrigation and abundantly manured. 5. Indian corn, or flax. After the flax is cut, at the end of June, millet is sown, which comes to maturity in October. Sometimes another crop of maize is taken in the sixth year, before returning to wheat.

One point of importance in respect to loamy soils in warm, dry climates is that, immediately after a crop has been harvested in midsummer, the land may be put into proper condition to be ploughed and worked for the introduction of a new crop simply by wetting it. This practice is common at the South of France, and on the west coast of South America, also. In a similar sense, when root-crops are to be "lifted" in the autumn at a dry time, much labor may be saved if the soil is softened by irrigating it. Formerly, when madder was cultivated in France, this idea was often put in practice.

Irrigation is Widely practised.

In countries such as New and Old England, Switzerland, Northern and Central Germany, and the North of France, irrigation is seldom applied to any other crops than grass and garden vegetables, because for the production of grain and most kinds of fruits it is essential that the soil shall be dry rather than wet during the latter part of the crop's life, and especially at the time when such crops are approaching maturity.

In northern countries many soils are sufficiently charged with water naturally by the rains of winter to ensure the production, on the average of years, of fairly good crops of grain, and to permit the growing of orchards, also, without need of any additional water other than that brought by the summer's showers. But in many hot countries water must be supplied artificially to all kinds of crops. That is to say, in the lack of the soaking rains of winter, irrigation must be resorted to in order to charge the land with water in the spring for the use of the young grain-plants at the grass-

like stage of their development; and when the crop has become somewhat older irrigation must again be applied from time to time, though carefully, to prevent the land from drying out too completely before the crop has become mature enough to ensure perfect ripening of the grain.

It is noteworthy, also, that irrigation is important in regions of high hills, even in those where showers are frequent, because the steep slopes shed most of the rain-water which falls upon them, and because moisture dries out quickly from the soil of sloping fields, on which the sun beats powerfully.

As applied to mowing-lands and pastures, irrigation is common in Germany, in Switzerland, and in the Tyrol, as well as in some parts of France and Spain, while in several provinces of Italy the practice is said to be well-nigh universal. In Italy, irrigation is applied to Indian corn also, and to rice, of course, though rarely, it is said, to other kinds of grain, though trials made by Gasparin, in France, indicated that on watered fields 10 kilos of wheat were produced for each 100 kilos of farm-yard manure expended; while on similar fields not irrigated only 3.4 kilos of wheat were obtained for each 100 kilos of manure. Gasparin insists on the great advantage which may be gained in dry climates when a wheat-crop is saved by irrigating it in the spring, in case it should happen to be menaced by drought at that season. He urges also that, in countries where the summers are hot and dry, irrigation permits the farmer to sow wheat much later than would be practicable if the dependence were to be placed on the moisture naturally held in the soil in the spring. But in India, grain, sugar-cane, cotton, and a great variety of other crops, are habitually irrigated. As regards grain, in particular, much depends in any given locality upon the time of year when rains fall, and upon the amount of rain. In Japan also, as well as Algeria, and in many other tropical or arid countries, irrigation is frequently practised as a matter of course.

It has been said of upland soils in Southern France, and especially of droughty years, that after the soil has dried out in the spring vegetation comes to a stand-still, sometimes from May until the middle of October. Hence the growth of annual plants in particular stops precisely at that moment when the temperature is specially favorable for their development, if only moisture were within reach. Here it is that irrigation is at its best, and is

really necessary for all kinds of crops, in that it supplies the needed moisture, and enables the plants to grow freely. (Gasparin.)

Lucern under Irrigation.

In France it is said that water-meadows of the first class yield some 6,000 lbs. of hay and rowen to the English acre, taking one year with another. At the East of France, Boussingault estimated the average yield of hay and rowen from well-managed meadows at 4,400 lbs. to the acre. At the South of France lucern is often irrigated, with great advantage. On dry land this crop does not start at once to grow after it has been mown, but when rained upon or watered a new growth begins at once; so that, by means of irrigation, it is easy to obtain many and heavy cuttings throughout the entire summer, and to obtain, moreover, a full crop the first year the land is laid down. In the case of sainfoin, also, the second cutting on irrigated land is said to be almost as good as the first.

Gasparin describes one instance, in which 14 hectares of sandy, gravelly land, from which wood had just been cleared off, were bought for $3,600, and seeded with lucern. By means of irrigation there was produced on this land, in a single year, 350,000 kilos of lucern hay worth $3,600, i. e. the first cost of the land. In another instance some calcareous, clayey land had been habitually rented for $26 per year and hectare, but after it had been converted into a water-meadow a rental of $65 was obtained.

In certain districts of Spain, also, where lucern is habitually irrigated and heavily manured, enormous quantities of hay are obtained. Barral has reported one instance where there was harvested, in the course of one year, as much as 22,000 kilos of dry lucern hay to the hectare, i. e., 9.7 tons of hay to the acre. Hilgard has told a similar story of California, where, in Tulare and Kern counties, 5 cuts of lucern have been taken from irrigated land in a single season, and 10 tons of hay have been made. Extraordinary results have been obtained, also, with sorghum, Egyptian corn, and pearl millet, three heavy cuttings of which have been made, for forage, on irrigated land in a single year.

According to Llanrado, the lucern fields near Saragossa are irrigated 31 times a year on the average, at the rate of 1,000 cubic metres to the hectare at each watering, so that, altogether, the water would be equal to a layer about three metres thick. The

fields are mown six times a year, during 8 or 10 years; and there is obtained each year, all told, between 15,000 and 16,000 kilos of hay to the hectare, i. e., 6.5 to 7 tons of hay to the acre. The first and the last cuts each yield about 2,200 kilos of hay, and each of the 4 intermediate cuts about 3,000 kilos.

But, as has been pointed out by Gasparin, these "miracles of lucern" are obtainable only on moist or irrigated land, in regions warm enough for olive-trees to thrive. He insists that in the spring lucern does not begin to shoot up until the soil has become warm enough to mark 54° Fahr., and that its growth is checked in the autumn as soon as the temperature of the soil has fallen to 54°. In temperate regions there is really only a comparatively short interval during which lucern can truly thrive.

In Switzerland it is said that from 3 to 4 tons of hay to the acre are cut from irrigated meadows, beside a couple of clippings of grass that are fed to cattle in stalls.

Effect of Water and Heat.

In general, the practices of tropical countries, in many parts of which irrigation is an absolute necessity in order that plants may constantly be kept succulent enough to grow, must not be compared too closely with the requirements of temperate lands, although it is most conspicuously true that irrigation is at its best in hot climates. It has often been remarked that when a sufficiency of moisture is available, a high temperature will go far towards compensating for a small supply of manure, and that, conversely, a deficiency of heat may be made good in some part by large applications of manure. In the words of Townsend, writing of Spain, "It is astonishing to see, in a warm climate, the rapid growth of plants that are well supplied with water. The smallest cutting of a vine will, in the space of 15 or 16 months, cover the front of an extensive edifice, or form a spacious arbor from which the assembled family may gather in abundance the most luxurious grapes. In such a situation the seeds of limes, oranges, and lemons will in four or five years produce a shady grove; and mulberry-trees, when wholly stripped of their leaves for the nutriment of silkworms, will again in a few days be covered thick with foliage. Thus Adanson, in his account of Senegal, informs us that, when everything green has been devoured by locusts, not a vestige of their destructive progress can be discovered after the lapse of a few days.

A method of irrigating wheat, practised in Sicily and south-eastern France, has been described by Gasparin as follows: The wheat is sown early in November, either on land which has been well worked and manured, or which has been brought into good condition by the preceding crop. In order to success, the land must be permeable, and must not repose on a subsoil that would hinder drainage. In order to control the water supply, the land is laid off in beds from 3 to 6 feet wide, with furrows between them which are 9 or 10 inches wide and 2 or 2.25 inches deep. When rain is lacking in the spring, and the winds have dried out the soil, and the mean temperature has reached 55° F., water is let into the little furrows between the beds, which are kept full for a long time, so that the earth of the beds may be soaked by way of infiltration.

Care is taken not to submerge the beds, for that would "settle" the land and hinder the growth of the crop. Later in the season, in case it should appear that the crop is suffering from drought, the process of soaking is repeated; but the water is rarely turned on more than twice, and often a single soaking is sufficient. Admirable crops of wheat are obtained, and the only danger is that the plants may lodge. After the grain harvest, the land is laid under water for a time and then left for a few days to dry out, and potatoes, maize, millet or beans are planted, the management of the land and the water being similar to that employed for the wheat. These stolen crops grow freely in the moist earth during the heats of July, August and September, and yield abundant harvests. But so much of the store of fertility is used up that an abundant manuring has to be given for the crops of the next year. In another French method of irrigating wheat, water is applied four times, as follows: first on the bare land before seeding it at the beginning of October; second in April, when the mean temperature of the air has reached 54°; third when the crop is in blossom; and the fourth some days after the third. The last two wettings cause the plants to blossom more freely, and consequently to bear more grain. The yield of grain is from 2,800 to 3,250 lb. to the acre.

Ruin caused by the Destruction of Irrigation Works.

With regard to other countries, the underground canals in Persia, and the cisterns, water-tanks, and irrigation ditches in India, are prominent features everywhere, to judge from the constant

mention of them by travellers, and so it was formerly in Palestine and Syria. According to Mr. Marsh, it is to the destruction of the ancient reservoirs that the diminished fertility of these countries must be attributed. The surface of Palestine, he says, is composed in great measure of rounded limestone hills, near the tops of which reservoirs were hewn in the rock to retain the winter's rains, while the declivities were terraced. So long as these cisterns were in good order, and the terraces kept up, the fertility of Palestine was unsurpassed; but when misgovernment and wars occasioned the neglect or destruction of these works, traces of which still meet the traveller's eye at every step, when the reservoirs were broken, and the terrace walls had fallen down, there was no longer water for irrigation in summer, the rains of winter soon washed away most of the thin layer of earth upon the rocks, and Palestine was reduced almost to the condition of a desert. So, too, in the neighboring countries. In Egypt, as Mr. Marsh explains, evaporation and absorption by the earth are so rapid, that all annual crops require irrigation during the whole period of their growth. As fast as the water of the river retires by the subsidence of the annual inundation, the seed is sown upon the still moist, uncovered soil, and irrigation begins at once. Upon the Nile, the creaking of the water-wheels, and sometimes the movements of steam-pumps, are heard through the whole night, while the poorer inhabitants unceasingly ply the simple bucket and sweep, laboriously raising the water from trough to trough by as many as six or seven stages when the river is low. The quantity of water thus drawn from the Nile is enormous.

The conditions, as regards soil and climate at least, under which irrigation is practised in Italy, would seem to be nearly akin to those which obtain in New England. According to Mr. Marsh, the summers in Northern Italy, though longer, are very often not warmer than in New England; and in ordinary years the summer rains are as frequent and as abundant in the former country as in the latter. Yet in Piedmont and Lombardy irrigation is generally practised. In the great alluvial plain of Northern Italy, where irrigation is so common, the soil is very extensively underlaid by beds of pebbles and gravel brought down by mountain torrents at a remote epoch, just as multitudes of loamy fields in New England are underlaid by the gravelly glacial "drift." In the year 1856, about four-thirteenths of the old kingdom of Sardinia were

irrigated, — some 600,000 acres, namely: In Lombardy there were 1,100,000 acres, and in France about 300,000 acres. Mr. Marsh held that there was every reason to believe that the practice of irrigation will greatly increase in the south of Europe. He estimated some years ago that the artificially watered soil of Italy would be doubled, and that of France quadrupled, before the end of this century. He tells us that two of the canals in Lombardy, by which some 250,000 acres of land are irrigated, were dug in the twelfth century.

As regards the United States, it was computed in 1890 that irrigation is practised on some 3,600,000 acres of land between the Pacific Ocean and the Mississippi River.

Civilization arose in Irrigated Regions.

Historians have called attention to the remarkable fact that civilization had its rise in irrigated countries. In order that a nation may become civilized, agriculture must needs be practised, and it must be practised with certainty. In Egypt, for instance, the harvests may ordinarily be foretold and controlled, and there man first became civilized. Peru, also, a rainless country, which was skilfully irrigated by the Incas, has been called the Egypt of civilization of the Western Continent. "In most countries, the cultivation of the soil is uncertain. From seed-time to harvest, the meteorological variations are so numerous and great, that no skill can predict the amount of yearly produce. Without any premonition, the crops may be cut off by long-continued droughts, or destroyed by too much rain. Nor is it sufficient that a requisite amount of water should fall; to produce the proper effect, it must fall at particular periods. The labor of the farmer is at the mercy of the winds and clouds. With difficulty could a civilized state originate under such circumstances. . . . But there is a country (Egypt) in which man is not the sport of the seasons, in which he need have no anxieties for his future well-being — a country in which the sunshine and heat vary very little from year to year." (Draper.)

In consonance with this fact, it is noticeable that the art of irrigation attained a high degree of excellence in many places at a very early period, and afterwards suffered a great decline, when the countries that practised it were conquered and overrun by nations ignorant of the art. Not only did this happen in Palestine and in Persia and the adjacent countries, but the same result came

to pass in Spain, and in Mexico and Peru when the Spaniards overran these countries; and so it was, too, in India, when the English first took possession of the land. The only difference was, that in some of these cases, as in Palestine, the irrigation works were completely destroyed, while in others they were merely neglected or curtailed, so that the development of the art was checked. The Moors who took possession of Spain in the sixth century were skilful irrigators, and they constructed great works to this end all over the country, and in the southern part of France. But when the Spaniards expelled the Moors, the greater part of the irrigation works went to ruin. Just so it was in Peru and in Mexico, for the invaders were less civilized than the invaded in this particular respect. But in spite of their lack of interest, the Spaniards did, nevertheless, learn enough about irrigation to keep the art alive, after a fashion. Indeed, in some parts of Mexico they constructed extensive works, and it was from contact with the Spaniards in California that Americans learned their first lessons as to the practice of the art.

There is every reason to believe that irrigation will henceforth be practised in all parts of this country, now that a multitude of people are interested in the matter, and have become familiar with its methods and results as witnessed on the Pacific coast. Not that it is probable that the Americans will speedily attain to the same kind of particularity and perfection which was reached by the Spanish Moors. It is not at all likely that our farmers will try to carry out the details so nicely, so methodically, and so systematically as the Moors did. But it is to be expected that they will adapt the art very completely to the requirements of the present day, and obtain highly profitable results by means of it. At any moment now it may become fashionable to establish irrigation works in the Atlantic States, and for the residents of these States to insist upon the merit of the art as if it were a new discovery.

In India, the English, after many years of comparative neglect, took up the matter zealously, and they have done much to extend and improve the methods of irrigation which are practised there.

Method of the Moors.

The following citation from Birkbeck relates to the Moorish system. In describing the southeasternmost corner of France, where it touches the Spanish border, he says: "How this country was originally laid out so judiciously, with channels of irrigation

systematically arranged for the benefit of the whole, is a mystery I have not heard explained. A master's hand seems to have planned and executed all, before the appropriation of the soil; otherwise private interest would have interfered and marred the design. Every man now finds a canal for bringing on water passing above his field, and a canal for drawing off water at the bottom, the latter serving in its turn to let on water for the land below."

"The manner of applying the water is extremely simple. A dam is made across the upper channel, from which the water flows gently into a furrow made by the plough along the higher side of the field, and in a few hours soaks through the whole soil, until it reaches the lower side, which completes the operation. The following course of crops, which is one of the usual practices of the district, may show what this amphibious husbandry can effect. In August they scratch the wheat stubbles with their little Roman plough, which does not turn a furrow, nor move a fourth of the surface; they then sow annual clover [crimson clover, T. incarnatum], and plank it in by dragging over the land a plank, on which a boy rides, thus breaking the clods and smoothing the surface. The weeds and stubble are but little affected by these substitutes for ploughing and rolling. But this is no matter, for, the water being now introduced, the clover starts instantaneously, as it were, and is knee-deep by October or November, when it is fed off by sheep. Water is applied from time to time, and in January or February the clover is fed again. Finally it is mown for hay in May, yielding a heavy crop. As soon as the hay is off the land, another scratch is given, millet or beans are sown, irrigation goes on, the crop is reaped, and the ground receives four ploughings as a preparation for wheat, which is sown in October or November. . . . . This is the history of one year; and is a familiar and constant practice in this region."

Some Evils of Irrigation.

It is but fair to say that the practice of irrigation is attended with certain drawbacks, excepting in broken and hilly countries, like some parts of New England, where springs and rivulets are numerous. According to Mr. Marsh, any large-way system of irrigation necessarily brings in its train very serious evils, both economical, social, political, and, as he might have added, malarial. The construction of canals and their immensely ramified branches,

and the grading and scarping of the ground to be watered, are always expensive operations, and they often require an amount of capital which can be commanded only by the state, by moneyed corporations, or by very wealthy proprietors.

The capacity of the canals must be calculated with reference to the area intended to be irrigated; and when they and their branches are once constructed it is very difficult to extend them, or to accommodate any of their original arrangements to changes in the condition of the soil, or in the modes or objects of cultivation. The flow of the water being limited by the abundance of the source, or the capacity of the canals, the individual proprietor cannot be allowed to draw water at will, according to his own private interest or convenience, but both the time and the quantity of supply must be regulated by a general system, applicable, as far as may be, to the whole area irrigated by the same canal; and every cultivator must conform his industry to a plan which may be entirely at variance with his special objects, or with his views of good husbandry.

The clashing interests and the jealousies of proprietors depending on the same means of supply are a source of incessant contention and litigation, and the caprices or partialities of the officers who control or of the contractors who farm the canals, lead not infrequently to ruinous injustice towards individual landholders. In Europe, these circumstances have discouraged the division of the soil into small properties, and there is a constant tendency to the accumulation of large estates of irrigated land in the hands of great capitalists, and consequently to the dispossession of the small cultivators, who pass from the condition of owners of the land to that of hireling tillers. The farmers are no longer yeomen, but peasants.

Manifestly, however, these evils, as set forth by Mr. Marsh, are of the same general character as those which accompany all corporate action, and all kinds of corporate enterprises. They are cited here because they enforce the lesson that, if nations so much less favorably situated than the New Englanders are can afford to submit to the inconveniences enumerated for the sake of the benefits which irrigation offers, there must be all the more reason to condemn the inertness of those American farmers who, by utilizing the waters of their own brooks, might gain all the advantages that are to be had from irrigation without encounter-

ing any conflicting interests, or opposition, or annoyance of any kind. One noteworthy point, illustrated by Italian irrigation, is that the farms in that country are to-day extremely fertile. Exhaustion of the land is not thought of, though the art of irrigation is known to have been extensively practised there ever since the 11th century, at least.

Ways of obtaining Water.

The cost of irrigating land will necessarily vary widely, according to the manner in which water is obtained. Naturally, the simplest and easiest method of obtaining water is to direct the flow of some brook or spring lying at a higher level than the field to be irrigated. In this case it will be comparatively easy to estimate the cost of the operation, which will be determined by the distance the water has to be brought, and by the number and character of the impediments to be overcome in the bringing. This method of procedure is necessarily restricted to the vicinity of hills and mountains, though there are many districts where permanent profit may be gained at trifling cost by utilizing the waters of hillside rills.

But wherever irrigation is practised on the large scale, it is essential that an ample supply of water shall be at command constantly during the growing season, and it is customary in this case to dam up the head waters of brooks or rivers, so that the rains of winter may be held in store, to be gradually expended and put to use whenever the water is needed. In this case long canals or aqueducts, and often enough costly bridges or embankments to support them, are required in order to the distribution of the water, and there are other incidental expenses which help to confine such undertakings to hot and dry or arid countries, where the profits to be got from irrigation are exceptionally large, because the soils are naturally fertile, and cannot be put to use without the aid of water.

In default of a supply of flowing water, there are several methods of lifting water which may occasionally be employed with advantage in agriculture and horticulture. The hydraulic ram is an efficient and an inexpensive instrument, which can do a great deal of work without need of much supervision. It might be used for purposes of irrigation in many situations. It is surprising that an instrument in such common use in this country for pumping water into houses and stables should be so seldom employed for watering

fields. There are aspirating siphons, and water-lifters, actuated either by a head of water or by steam, which are extremely simple both as to their construction and their manner of working, since the motor acts directly without the intervention of any complicated machinery.

Windmills also, such as were formerly abundant on the seacoast of Massachusetts in the days when salt-works were necessary or profitable in this region, might sometimes be used to lift water for irrigating, though their action is necessarily intermittent, and there must be reservoirs connected with them to be filled when the wind permits the pump to act.

Many varieties of steam-pumps can be run at small cost, some of them with entire safety also, and the water thus lifted can often be applied directly to the land without the intervention of storage reservoirs. On farms where steam-power is used, it might often be practicable to irrigate a considerable field by causing the engine to drive a pump at times when it could conveniently be spared for this purpose. So, too, there are cheap engines, actuated by hot air obtained from an ordinary stove. These engines need but little attention, and are no more dangerous than a cooking stove. Even where an engine is required, it is an easy matto lift water to a moderate height at small cost. A slow-moving, great wheel-pump will scoop up water very cheaply to the height of a few feet, if only time enough be allowed for it to work; and such a pump may be driven either by steam or by water-power if it be at hand. But for the undue cost, the wheel might be driven indeed, if need were, by horse power, or by means of cattle, or even by manual labor, as at the East. In some situations where the force of electricity can be made available at small cost, it will doubtless be found to be a convenient means of working irrigation pumps.

At some future time, doubtless, pumping engines will be driven directly by the heat of the sun, for there is everywhere an enormous amount of force to be had for the taking from hot sunshine. Several engines for utilizing the sun's heat as a motive force have already been devised by Ericsson and other inventors. It is to be said of these machines that while they are not lacking in efficiency, the first cost of erecting them is so large that they cannot compete at present, economically speaking, with engines driven by means of coal. None the less is it true that the results already

obtained indicate that at some future day the ordinary methods of agriculture may be entirely changed in many countries — perhaps in most countries — by the adoption of methods of irrigation founded upon pumping water by means of engines driven by the sun's heat. Even in hot countries, there are numberless localities where rivers flow constantly throughout the summer season and bring abundant supplies of water from distant mountains.

Reservoirs for Irrigation Water.

Where irrigation is practised in the large way, it is customary, as was just now said, to build great dams across brooks and rivers to hold back and store the water in ponds or lakes which can be drawn upon at will. Such constructions are often very costly. But as regards the reservoirs or tanks into which water is pumped for the use of a single farm, there is usually no need that they should be of expensive construction, though it is well enough to make them sufficiently capacious. In general, it may be said that a layer of puddled clay will hold water, and that a methodized mud-puddle might, in many instances, serve an excellent purpose. Explicit directions for the making of cheap pools and ponds are given by the early English writers, and a good deal of attention has been given to the subject in Europe, as bearing upon the making of fish-ponds, ornamental waters, and field reservoirs for cattle. In some tolerably firm soils, a mere coating of cement applied directly to the soil is said to be sufficient to make a water-tight hole; but it would have to be carefully shielded from frost. And here, in fact, is the weakest side of irrigation, in regions where the winters are cold. In such countries the risk of damage from frost must always be a great hindrance to the establishment of dams, cisterns, reservoirs, terraces, or constructions of any kind.

Modes of applying Water.

It would be quite beyond the scope of this work to attempt to describe in detail the mechanical devices by means of which water is applied to the land in systems of irrigation. Many special treatises upon the subject have been published, and may be obtained through any bookseller. It is to be remembered, however, as regards hay-fields, that many of the complex and elaborate arrangements of ditches described by the older authors were devised at a time when grass was mown wholly by hand, i. e. with scythes, before mowing-machines had come into use. To meet

the requirements of these machines, narrow open ditches, with steep sides, had better be dispensed with in so far as may be possible.

One simple way of irrigating where the land is somewhat sloping, and in grass, is to bring the water into a long ditch at the head of the slope, and to lead it thence into smaller ditches, from the sides and ends of which project still smaller cuts. By means of gates and check-boards of the simplest conceivable construction, the flow of water into the several ditches is regulated both as to its quantity and its direction. At the heads of the smaller ditches a mere sod is often used as the gate. By treading the sod down firmly in the mouth of the ditch, the flow of water is checked, and by taking up the sod the ditch is opened.

The entire system of ditches is so arranged that a thin but regular sheet of water may be made to flow at will over any and every part of the field. Whatever water does not sink into the soil is collected in another main ditch at the foot of the slope, and so carried off; or, where the slope is long, the surplus water may go to feed a second complex of ditches similar to the first. After the flow of water has been kept up for two or three days, the supply is shut off, and the field is allowed to dry out.

In Italy the surplus or drainage water which collects at the bottom of the slope is highly esteemed, since in that country it has almost always passed over richly-manured land, and has thus become more highly charged with fertilizing matters than it was originally. But in Switzerland, where the water itself is regarded as manure, the farmers have observed that "When the water is suffered to flow over too large an extent of land its virtue is invariably diminished." The Italians attach considerable importance also to the fact that the temperature of the water becomes higher as it flows over the land, and is in so far better fitted to promote nitrification and to force the young grass.

The operation of flowing is repeated as often as the weather may dictate throughout the season. The idea is, that a thorough soaking should be given to the land at proper intervals of time, but that the water should never be left on long enough to exclude air from the pores of the soil for more than a comparatively brief space. If air were thus excluded, there would be a risk of exciting reducing actions which would make the land cold and sour, so that useful grasses would be killed, and the growth of rushes,

sedges, and other swamp plants be encouraged. In irrigating meadows, it is held to be essential to have ready means of drainage in order to prevent any stagnation of water on the land. As Townsend insisted, long ago, "Stagnant water is at all times unfriendly to meadows. Such water may remain upon the surface of the soil for weeks or months, subject to decomposition, but instead of being in this state beneficial, it is injurious to crops. In water-meadows, we uniformly observe that it is not humidity which does good, but a thick sheet of water flowing incessantly night and day for a certain period over the surface."

Wherever land is irrigated, thorough drainage is a highly important condition for success. In the absence of a ready outlet for the ground-water, crops might suffer severely in case a heavy rain-storm should occur just after a field had been drenched with irrigation water. It is a rule, also, that cattle should be kept out of irrigated meadows, lest they poach the land so that water may become stagnant in spots upon it. It is a familiar fact that even in the moist climate of Holland, much low-lying and very damp land gives extremely good crops if only pains are taken that the water within the soil shall not become stagnant.

Irrigation keeps Land "sweet."

It is noteworthy that one prime merit in irrigation, where good water is properly applied, consists in its killing out mosses, sedges, and the like, from low-lying meadows. The inference is, that this result is accomplished by the water's washing out from the soil soluble humic acids, sulphides, ferrous sulphate (?), and other products of processes of chemical reduction; — products, that is to say, which are prejudicial to the growth of good grasses, but which can be supported by the inferior plants just mentioned.

By thus killing off the bad plants, and encouraging the growth of better grasses, irrigation may not only increase the yield of hay upon a meadow, but improve the quality of the hay. In a similar sense it is to be remarked that brook-water which is actually moving (living water, as the term is) is far less destructive to some really worthy grasses than cold or stagnant water.

Ribbon-grass, for example, will grow freely even in situations where a thin layer of brook-water flows over the land wellnigh continually. Such water probably contains a good deal of air in solution, for one thing; and for another, it must dilute and wash away any soluble hurtful products which may form in the wet soil.

But if the water were left for so long a time simply to stand upon the land, or to soak into it, and were not continually in motion, the grass would be liable to perish.

Distributing Ditches.

It often happens that upon a hillside a single ditch drawn across the head of the slope will be sufficient to spread the water tolerably equably over an entire field. Between the system depending thus upon a single ditch, and the more elaborate system just now alluded to, there may be devised an almost infinite variety of arrangements. Practically, the farmer will make his complex of ditches more or less methodical according to the lay of the land and the character of the inequalities upon its surface. But the irrigation, considered as a method of manuring poor land, will manifestly be the more complete in proportion as the number of the distributing ditches is greater, because of the fixation of fertilizing matters by the soil where the water first comes in contact with it. In case there is but a single ditch at the top of a slope, the dissemination of the fertilizing matters will be more or less restricted, and it has on this account sometimes been found well to change the position of the ditches occasionally when this could be done without much trouble. Among irrigators, there is an adage, "The more gutters, the more grass."

An ingenious modification of the single ditch at the head of a field has been invented in California and applied there for irrigating arable land and orchards. This plan has obviously much merit in that it is convenient of application, that it economizes water, and applies the water gently and equally. "A small wooden flume, 8 or 10 inches square, is laid along the upper side of a ten-acre field. At intervals of 1 to 3 feet, according to the nature of the ground and the crop to be irrigated, one-inch holes are bored, with a small wooden button over each of them to regulate the flow. This flume costs but a trifle, is left in position, lasts for years, and is always ready. Into the flume water is turned, from an irrigating ditch, under a head of about 20 inches, — or sometimes of 25 or 30 inches. By removing the buttons from the holes in the flume, the water is let out in streams of from one-sixth to one-tenth of an inch each, making in all from 120 to 200 small streams. To receive these little streams, from 5 to 7 furrows are made between two rows of fruit-trees, 2 furrows between two rows of grape-vines, and one furrow between rows of Indian

corn, potatoes, etc. It may take from 15 to 24 hours for one of the streams to get across the field. They are allowed to run from 48 to 72 hours. The ground is then thoroughly wet in all directions and to a depth of 3 or 4 feet. As soon as the ground is dry enough, "cultivation" is begun and kept up from 6 to 8 weeks before water is used again. Only when the ground is very sandy, is it necessary to make basins around the trees." (Van Dyke.)

The following analyses by Mayer exhibit some of the differences in the composition of incoming and outgoing water, as actually taken from an irrigated field. A litre (1,000 grams) of water contained the following amounts of dissolved matters, in milligrams.

	Live Water, i. e. incoming.	Drain Water i. e. outgoing.
Lime	23.1	12.4
Alumina and oxide of iron	2.4	3.5
Phosphoric acid	trace	trace
Potash	4.2	2.9
Matter insoluble in muriatic acid, after evaporation and ignition (silica?)	11.1	13.3
Organic matter, etc.	7.1	10.2
Residue left on evaporation, i. e. sum of the dissolved matters	81.8	61.6

As is set forth in the following tables, highly interesting experiments have been tried by Koenig, who, in the month of March, dissolved several kinds of fertilizers in water that was to be used for irrigating, and determined how much of each of the more important constituents of these fertilizers was left in the outgoing water as it passed away from the field after having been used: —

Trials with Superphosphate, and Salts of Potash and Ammonia.

There was contained milligrams of	Potash.	Chlorine.	Ammonia.	Phosp. Acid.
In 21.6 litres of incoming water	410.4	527	170.6	339.1
In 19 litres of outgoing water	239.4	522	45.6	131.1
Decrease, milligrm.	171.0	5	125.0	208.0
Decrease, per cent	41.6	1	73.2	61.3

Trials with Nitrate of Potash.

There was contained milligrams of	Potash.	Nitric Acid.
In 21.6 litres of incoming water	1550.9	1527.1
In 19 litres of outgoing water	201.4	456.0
Decrease, milligrm.	1349.5	1071.1
Decrease, per cent	87.0	70.1

One system of irrigation applicable to perfectly flat land, as at the sides of a brook, consists in throwing up with the plough a

series of land-beds, each of which is provided with a shallow ditch at the crown or summit, while there are deeper ditches at the base of the bed upon both sides. The water of irrigation is led into the upper ditches, at the crowns of the land-beds, and made to flow down the slopes upon both sides of the beds, and to escape through the ditches at their feet.

It is noteworthy that practical men in France and Switzerland direct that when mowing fields are to be irrigated in hot summer weather, the water should be let on by night, and shut off during the day; and that no water should be applied for a week before the grass is mown. The idea is to hinder in some part the enormous waste of water by way of evaporation. During the night evaporation is at a minimum, and so much water will have sunk into the earth before morning, that comparatively little of it can be wasted by the heat of the next day. Even after the hay has been harvested, and time enough has been allowed for the cut stalks to become dry, water is let on by night only, when the field is to be drenched, and it is shut off by day. The practice is clearly philosophical from the chemical point of view; food is provided for the grass by night, and the light and heat of the day are permitted to act without hindrance upon the growing crop. But the chief advantage gained is in the economizing of water.

This fact was conspicuously illustrated by the experience of certain English farmers who formerly used liquid manure in a manner which will be described directly. Thus, an instance has been reported where, at a time of drought, 12,000 gallons of the liquid were applied per acre, to freshly planted cabbages, upon land that was in a very dry state. There was water enough applied to cover the whole surface of the field about half an inch deep, but that part of the liquid which was distributed at midday dried up so nearly completely in the course of a few hours that the benefit which might have been derived from so large a supply of water was well-nigh lost; whereas, from that part of the field to which the liquid was applied in the evening the loss by evaporation was but small, and the advantage to the crop was correspondingly large.

Sanborn reports, as the result of experiments made in Utah during 3 seasons, that the total yield of the wheat-crop (grain and straw) was about 15 % larger on land that was irrigated at sunset, 3 times during the growing season, than on land irrigated

at 10 A.M. The proportion of grain to straw was slightly larger in the case of the crops which were watered in the daytime; it was thought because the development of foliage in those crops was somewhat checked by the lower temperature which was found to prevail on the land thus watered by day.

Some kinds of Grasses prosper when Irrigated.

Whenever it is proposed to irrigate grass-land, care must be taken that the grasses grown there are of kinds fit to be irrigated. Unless this point is attended to, no permanent advantage would be gained by bringing water upon a dry field. In the milder parts of Europe, Italian ray-grass has been found to be specially well suited to be grown on irrigated meadows. In fact, this variety of grass seems to be dependent on irrigation for its proper development. By experiments made in France it was found that it degenerated very rapidly when sown on poor, dry soils. But when irrigated and manured its growth is very rapid. It may be mown thrice in its first year. In the vicinity of Milan as many as eight cuttings are sometimes taken in a single year, and nearly 7 tons of hay to the acre have been obtained occasionally. The hay is held to be of better quality than that from the other kinds of ray-grass.

One important consideration must not be lost sight of, and that is the power which irrigation gives the farmer to regulate the temperature of a field. In case there is danger of frost, for example, either in the spring or in the autumn, it will merely be necessary to flood the field through the night in order to protect the grass from harm. In the excessive heats of summer, also, the coolness resulting from the evaporation of the water from the moistened soil keeps down the temperature of the plant to a healthy limit.

Sewage Irrigation.

In the neighborhood of cities and large towns it has occasionally been found practicable to irrigate land with water from the sewers, and since the sewage is more highly charged than ordinary water with fertilizing matters, excellent results have occasionally been obtained in this way. The irrigated fields outside of Milan and Edinburgh have long been famous, and of late years portions of the sewage of London and Paris and Berlin, and several other cities, have been applied in a similar way.

I have myself examined the grass-land outside of Edinburgh, which is irrigated by the sewage of that city, and I can testify that

the published accounts of its wonderful fertility are in no sense exaggerated. The vigorous and rapid growth of the grass, and the number of crops obtained in the course of a year, as well as the size of these crops, are simply marvellous. The meadows in question begin in a narrow valley close to the city, and extend at intervals a distance of several miles down to the sea. There is a narrow, deep, open brook, which is manifestly natural, flowing through the middle of this valley, and carrying the sewage of a part of the town. Although the covered sewers of the Edinburgh streets, bearing much filth from cess-pools and water-closets, flow into this brook, I could not perceive that any unusual odor was given off by the water, except on very careful inspection. A stranger knowing nothing of the matter would notice only that the water of the brook is unusually dark and muddy. This freedom from odor is doubtless due to the circumstances that the brook falls away from the city rather rapidly, and that a great deal of ground-water from the higher parts of the city is constantly flowing into the brook together with the sewage. The coolness of the ground-water and the rapid fall tend to prevent the sewage from putrefying, and the access of ground-water dilutes it to a state of comparative sweetness. The rain-water from the streets of the city also flows through the sewers into the brook, and it was easy to see, from the pieces of drift-stuff hanging from bushes and the edge of the bank, that the brook is often swollen to an extent very much greater than at the time of my visit. Hence it is scoured periodically.

Thanks to the very considerable difference in level between the city and the meadows, the falling brook is made to work hydraulic rams at several points, so that as much of the sewage as may be desired can be pumped up to the highest edge of the meadows. There it is received in a long, and comparatively speaking deep ditch, running parallel with the brook, in which a considerable part of the mud which the brook-water held suspended is allowed to settle. From the top of this ditch, at distances of two or three feet from one another, small rills run off at right angles to the direction of the ditch, in such manner that the sewage-water can flow all over the slope between the upper ditch and the brook in the middle of the valley.

The grass, which comes to be of a rather coarse, but in no sense "sour" quality, is cut five or even six times a year, to be used as

green fodder; it is not made into hay. There is a constant succession of cuttings from early spring to late autumn, and after each cutting the plot is irrigated once. The luxuriance of the grass is most remarkable, and so is the freedom of the place from smells. I went across and around these meadows in all directions one warm day in the middle of September, and was quite unable to discover any offensive odor, either at the points where the rams were working, or where there are some rapids in the brook, or at the upper ditches, or at certain settling pools or ponds which occur at intervals in the course of the brook, and which have been made for the purpose of catching the mud which the brook brings down. At the feeding ditches scarcely any odor could be detected, although some of them were half filled with mud and filth in process of drying. At the rams there was a certain unpleasant smell, but it was very slight and altogether local. My companions, who were old citizens of the town, insisted that, even during the hottest days of summer, no appreciable odor can be detected on these meadows, so perfectly do the earth and the growing grass absorb and consume the putrescible matters of the sewage. When the water is shut off from the upper or feeding ditch, and the ditch becomes dry, a quantity of mud is scraped out from it, which is sold to market-gardeners to be used as manure. In the same way, mud from the settling pools is scraped out and sold.

It is said that, previous to the irrigation of this tract, it was a worthless, neglected, sandy waste. $2.50 the acre would then have been a high rental for land that is now let at the rate of $150. The original sand was dug out to be used in the city, and in its place rubbish of all sorts from the city was laid down; it being a comparatively easy matter to grade the surface of the rubbish so as to fit it for receiving the water evenly.

At Edinburgh the sewage is applied only to grass, though the deposit from the pools is used as a manure for all sorts of vegetables. The fact that this irrigation is so successful in the moist climate of Scotland goes to enforce the argument that irrigation must be looked upon as a chemical process. It will be noted, also, that the rubbish subsoil affords an open, porous land, much as if it were filled with tile drains.

In 1877 there were 400 acres of these "forced meadows" near Edinburgh, and they are said to increase gradually. The Craigentinny meadows, just now mentioned, were about 200 acres in ex-

tent, and they had then been irrigated for 30 years and more. They were laid down at first to Italian ray-grass and a mixture of other grass-seeds, but these artificial grasses disappeared long ago, couch-grass and various natural grasses having taken their place. The grass is sold green to cow-keepers, and yields from $80 to $150 per acre. One year the price reached $220 per acre. They get five cuttings between the 1st of April and the end of October. This farm of 200 acres turns in to its owner every year from $15,000 to $20,000, at the least calculation, and his running expenses consist in the wages of two men who keep the ditches in order. The sewage he gets free. The yield of grass is estimated at from 50 to 70 tons per acre. The total produce of the sewage irrigation at Edinburgh amounts to at least $30,000 per annum, taking one year with another. The grass goes to some 2,000 cows, and the milkmen all acknowledge that they cannot get any milk-producing food to compare with it for the same amount of money, notwithstanding the seemingly high price that is paid for the grass per acre. Of course the dung from these cows goes to fertilize other farm-land.

The only question is, whether there may not remain adhering to grass that has thus been bathed with sewage some germs of typhoid, cholera, or other vile diseases, which are propagated in human excrements. In view of what is now known of the modes of transmission of such diseases, it is difficult to look with entire complacency upon the acts of feeding cows with grass thus liable to contamination, or of throwing about such grass in stables where milk is exposed to the air during the operations of milking, straining, and canning. Indeed, cases have occasionally been reported where cattle fed with sewaged grass have suffered from persistent diarrhœa; and in one instance, in Germany, the death of many cows was occasioned by fungoid growths, which were developed on the grass of their pasture after it had been flooded by the overflow from an irrigated field.

Rank Grass may cause Hoove.

It is to be noted, withal, that there is always more or less danger in feeding rank grass to cattle, no matter from what source such grass may have been derived. Care must always be exercised when cattle are soiled with green-cut grass or with clover, for when eaten greedily or in excess, and especially when the grass has been kept for some little time after mowing, such fodder is

apt to ferment within the animals, and to cause their death through distention brought about by the gases which the fermentation develops. The name "hoove" is applied to this particular disease. Nevertheless it appears to be true, generally and practically speaking, that milk and beef from cows fed upon sewaged grass are perfectly healthful foods, and so are vegetables that have been grown on sewaged farms.

Opportunities to use City Sewage are rare.

There are few great cities in the world, however, beside Edinburgh and Milan, where arrangements such as those just described are possible. Any land so near a growing city as these meadows are to Edinburgh is far too valuable for buildings for agriculture to hope to lay any claim upon it. But, as has recently been done at London, Paris, Dantzic, Berlin, and several smaller cities, it is possible to pump the sewage into reservoirs, and then carry it through aqueducts for as many miles as may be necessary for the sake of fertilizing some barren waste. In such cases the only question to be asked, from the agricultural point of view, is whether the waste land could not be reclaimed more cheaply; whether, in fact, the money spent in erecting and maintaining the pumps, aqueducts, reservoirs, and works of irrigation might not be used to better agricultural advantage in importing guano or fossil phosphates, in composting peat, or bringing potash from the Stassfurt mine, or even in irrigating the land with mere water from some adjacent brook.

Generally speaking, the cost of carrying sewage to the farm-land simply for the sake of the fertilizing materials contained in it would be far too large to admit of any such project being seriously thought of. It is only where waste land is readily accessible, and so situated that the sewage can flow to it by mere force of gravitation, that this liquid can be economically employed as a manure. Usually the conditions in the vicinity of cities are such that a long and costly system of pipes would have to be carried over hill and dale for the conveyance of the sewage, and the liquid would have to be lifted by means of steam-pumps in order that it should flow through the pipes. But the cost of any such construction as these could not fail to be larger than the agricultural value of the sewage, and no farmer or combination of farmers could possibly afford to pay for them. Hence it follows that, whenever city sewage is to be conveyed to farm land, the necessary apparatus will have to

be built and maintained by the city, solely for the sake of getting rid of the filth.

It was thought at one time that sewage thus carried out from a city might be sold to the farmers, or even given to them gratis, in case they were indisposed to pay for it. But this scheme has been found to be impracticable.

There can be no question that sewage, even the weakest, would be a valuable manure if the farmer could find it at the edge of his field, brought there at little or no expense to himself, as is the case at Edinburgh, and if the privilege were allowed him of using the material at any moment, and in such quantities as he might choose, or of not using any at all if he thought best. It may be said, indeed, that the secret of success in irrigating with mere water depends largely on good judgment in applying the water at those moments when the crops actually need it, and on the power of the irrigator to decide correctly when to let on the water and when to shut it off. But such freedom of action as is implied in this statement would be quite incompatible with that constant and complete purification of the sewage which is the one particular point the city has to care for. Consequently, in most instances where sewage irrigation is practised, the cities have had to buy and lay out tracts for themselves, and to farm them also, at high cost.

Possibly a time may come, under some forms of government, when it would be economically practicable for a city to divide the irrigated tract into a number of small farms, and to lease these farms to the highest bidders, subject, of course, to stringent rules and regulations as to the manner of using the sewage. In this way the farmers would get the sewage for just what they could afford to pay for it; that is to say, the final result would come to this, after the value of the farms had been indicated by the experience of a term of years. The notion that sewage might be carried in pipes through considerable districts and sold to the farmers there resident is now regarded as chimerical, because of the absolute necessity of having a constant, definite, and certain outgo for the liquid. Nothing in the least degree uncertain or precarious can be permitted in this regard.

Sewage is good for Vegetables.

The experience of several European cities teaches that, though specially well adapted for manuring grass, sewage serves excel-

lently well for various roots and vegetables, notably for mangolds, celery, cabbages and rhubarb; care being taken, of course, not to let any of it come in contact with their leaves. Of England it is said that, as a general rule, only succulent plants should be sewaged. Cabbages, mangolds, garden vegetables, and similar green crops receive occasional dressings during the summer, when the plants are in full growth, and need to be fed; and in preparation for such crops, and for potatoes also, the land may be repeatedly drenched with sewage during the winter. Oats are said to do extremely well after sewaged mangolds, yielding 70 or 80 bushels to the acre, but in England no sewage is applied to the land while the grain-crop is growing.

Sewaged Grass.

Grass does better there than other crops, since it continues to grow through so large a portion of the year, and Italian ray-grass has approved itself to be supremely excellent. Good crops of it can still be raised on land which receives an enormous quantity of sewage. This grass admits of being irrigated almost constantly for some time, whenever it becomes necessary to do so in order to dispose of the sewage. It is said, however, that, in order to the best results, the grass-roots should be young and vigorous, and that the crop should not be left upon the land more than one year. The first year's growth is excellent, but after the second year the land needs to be broken up and reseeded.

In the words of Morton, "There is nothing more beautiful of its kind — nothing more convincing of the extraordinarily fertilizing agency which we have in sewage — than a field of Italian ray-grass ready for one of its earlier cuttings during its first year. Sown in August or early in September, and properly sewaged afterwards, it is in April of the following year the most wonderful picture of fertility which English agriculture knows. Let the land however be plowed up in the following November. Its second year will not be half so satisfactory; and the land will do better after a winter sewaging, in early potatoes removed for another ray-grass seeding in the following autumn, or for mangel-wurzel to be followed by cabbages in the third year, to be removed for an autumn seeding. In its second year, Italian ray-grass (sewaged) is rarely satisfactory; the same fertilizing agency is applied to it, but the plant itself is gradually becoming incapable."

Cases are on record however, as at Norwich (England), where sewaged Italian ray-grass has been treated as a permanent crop, being renovated annually with a bushel of seed to the acre, sown over the whole, and it has been claimed for this method that the oldest fields are best. At Norwich, the sewage is turned on about

the end of March and continued to the middle of October, being diverted from plot to plot as occasion requires. It is difficult, in the climate of England, at least, to make the rank sewaged grass into hay, but excellent results have been obtained there by storing the chopped grass in silos, as ensilage.

The difficulty of drying sewaged grass to hay, by ordinary methods, is illustrated by the following citation: "The brook Aston, which runs round the north and west side of Birmingham and receives the sewage of that part of the town, was diverted from its course many years ago and employed to 'float' 60 acres of meadow. In 1820 an additional 60 acres of worthless gravel were irrigated from the brook and thus made to yield abundant crops of grass; though previous to the irrigation the land had produced nothing but a short wiry grass scarcely worth the mowing. The meadows are grazed up to the middle or end of June, when the water is turned on for a week or ten days.

"The grass is mown some seven weeks from the time of removing the cattle. Then comes a great exercise of patience in getting the hay, which, in order to avoid a burnt rick, must be made and remade long after the period when ordinary grass would be fit to carry. The crop averages two tons to the acre, and though rather coarse, is with a little 'sweating' of the rick excellent in quality. If the hay is got off before the aftermath rises, the meadow is again floated for seven days, and in eight weeks the second crop, of about one ton to the acre, is cut and the meadow grazed during autumn; it is then floated, and again in the spring."

At Berlin, on a sandy soil, orchard-grass also was found to yield very large crops when irrigated with sewage; and mixtures of orchard-grass and Italian ray-grass did particularly well. Six cuttings of grass were obtained between May and October, or altogether nearly 80,000 kilo. to the hectare.

On the English sewage farms land-beds underlaid with tile-drains are provided, and the soil of these beds is soaked with the sewage more or less frequently and thoroughly. According to one account, the soil on which ray-grass is growing is soaked, for a few hours, two or three times, at intervals of a fortnight after the grass has been cut, the sewage being applied at the rate of 400 or 500 tons to the acre, which is equivalent to a layer of water about 4 or 5 inches thick. When the field is again mown, it yields some 10 to 16 tons of grass to the acre. In the course of the year, from 4,000 to 6,000 tons of the liquid are applied to each acre of land; 5,000 tons has been commended as a good annual application.

In experiments made at Rugby, by Lawes, large quantities of dilute town sewage were applied, during the spring and summer, to permanent meadows, the normal product of which, without the sewage, was more than 2.5 long tons of hay to the acre. There

was obtained an average increase of about 4 long tons of green grass (equal to about 0.75 ton of hay) for each 1,000 tons of sewage applied until the amount of the latter approached the rate of 9,000 tons per acre per annum. The largest yield was about 33 tons of green grass to the acre, and an abundance of green food for cattle was available during a period of 5 or 6 months.

In the 1st year of these experiments, 3,000 tons of sewage to the acre gave crops of nearly 15 tons of green grass per annum; 6,000 tons of sewage gave 25 tons of grass, and 9,000 tons of sewage gave more than 30 tons of grass. Taking the average of three years, 3,000 tons of sewage to the acre gave 22.25 tons of grass per annum, 6,000 tons gave 30.25 tons of grass, and 9,000 tons of the sewage gave 32.50 tons of grass, while a contiguous field not sewaged gave 9.25 tons of grass to the acre. In terms of hay, these crops were 5, 5.75, 6.50, and 3 tons respectively.

At Croydon, in England, eight cuttings of ray-grass are taken, the first in January and the last in December. Here the grass is irrigated from 24 to 48 hours each week. Vegetables, however, are irrigated not oftener than once a fortnight, and, if the season is wet, the watering is repeated only at intervals of 4 or 6 weeks. Excepting ray-grass, they would be glad not to irrigate any crop within a week of the time of harvest. In Wales, where the summer is shorter, the first crop of ray-grass is mown in April and the last in November, four cuttings being obtained in all.

It is evident that, on farms fertilized with sewage, large herds of cows could readily be maintained throughout the year by feeding out mown grass as such during the growing season, and as ensilage during the winter months.

Use of Sewage at Milan.

At Milan, in Italy, sewage irrigation and ordinary irrigation are said to overlap one another. Half the land in the neighborhood of that city is kept continually in grass. Thanks to the mild climate and to the warmth of the sewage, which, as it flows from a city, is always at a temperature above the freezing point of water, grass can be started very early in the spring by judicious flooding, and be kept growing until late in the autumn. Practically, at Milan they obtain a cutting of grass about a foot high on the 1st of February, and as many as nine cuttings in the course of a year. It is said that the 4,000 acres of meadow irrigated by the waters of

the canal of Vittabia, into which most of the sewers of Milan discharge, become so much enriched that the sods are removed occasionally and sold as manure; and that were it not for this precaution the grass would be rank and luxuriant, and would lodge so badly that it could not be mown.

It is to be remarked, however, that the use of sewage is exceptional in Italy, even near Milan, where a thorough system of overflow with simple water exists to a distance of about 10 miles to the southward and eastward of the city. As has been said, the irrigated fields are manured frequently with the dung of animals which have been fed with grass produced on these fields.

Irrigation is peculiarly applicable to grass-land, because the sod tends to prevent the soil either from gullying or from being puddled and encrusted by the action of water. Pasture-land may be flowed freely, even when its surface is very steep and very irregular, as is seen in Switzerland; but in order that other crops may be irrigated, upon hillsides at least, it is often necessary to build terraces, so that the soil may be supported and the water distributed. The expense of these constructions is so great that they are resorted to only in hot climates, where irrigation is an absolute necessity, and where there are no frosts of winter to destroy the embankments.

Subterranean Irrigation.

As regards crops other than grass, there is the trouble that, when water is repeatedly put upon ploughed land, it tends to float up and puddle the finer particles of earth, which subsequently, on drying, often make the surface soil so hard and stiff that the growth of the crop is hindered; even the soaking in of new supplies of water may be greatly delayed. It is on this account that, in Southern California, pains are taken to prevent the irrigation water from touching the trees or plants, or even from coming near enough that the soil immediately about them can become baked. Moreover, the surface soil is stirred with the cultivator as soon as it has become dry enough, in order to prevent baking. It was probably, in part at least, for the sake of lessening the risk of puddling, that trials were made in Germany some years ago, on a tolerably large scale, of several subterranean systems of irrigation. The fundamental idea in each case was to carry the irrigating water about beneath the surface of the ground in tile drains. This method is said to have been found useful on soils of fair

consistency, though not to be commended for porous soils, such as coarse gravels. One of its merits is, that much less water is needed than is usually expended in processes of irrigation. One observer has stated that not a twentieth part of the water used in the old system is required for the successful working of the underground plan.

It would seem at first sight that the expense of laying the tubes in this system must be so great that it could hardly be expected ever to come into general use, excepting, perhaps, as a sanitary device for disposing of sewage. But it has been claimed, nevertheless, that meadows can actually, in some instances, be laid out more cheaply in this way than by the old plan of scarping, since the water can now be fitted to the land, instead of fitting the land to the water as before. Land thus underlaid with tiles can never become springy or stagnant, because it is drained by the tiles. The land may either be charged with water, or water may be discharged from it, at will; and all kinds of crops can be grown upon the land, as well as grass, either in alternation with grass, or to the entire exclusion of grass.

In a similar sense, the English engineer Parkes proposed many years ago that, in the ordinary practice of draining land, all the drains of a flat field might be made to issue from a cesspool into which water from a higher level could be conducted. By stopping up the outfall pipe and letting water into the infall cesspool, all the pipes ramifying through a field might be filled with water which would gradually disseminate itself through the entire mass of earth above the level of the pipes, and to any desired height. In this way, water could be given to the roots of plants, particularly to those of the grasses; and when enough has been given, the whole of the water may be removed at will, and perfect drainage be established. He urged that in this way water could be introduced into the body of the earth, and applied by way of what he called "subirrigation."

This underground irrigation is extremely interesting from the scientific point of view, since the conditions which obtain in a field thus irrigated beneath the surface must be somewhat similar to those which exist naturally in fields where the ground-water stands at the best level for the growth of plants. Indeed, it is to be regarded as one great advantage of the tubes, that they act as drains in the spring to keep the land free from any excess of water, and

as conduits in summer to fill up the store of ground-water whenever the land has become somewhat dry. The surface of the land is left smooth withal, and unencumbered with ditches, so that it can be mown or cultivated, and that cattle can run upon it.

Another merit of the system is, that far less water is evaporated from the surface of the ground than must necessarily occur in ordinary irrigation. All the heat that would be expended in evaporating the water is of course left for warming the soil.

Doubtless a good deal of useful knowledge as regards the best methods of dealing with ground-water could be arrived at by experimenting with this system of subterranean irrigation, and carefully studying its efficiency under varying circumstances.

As regards the avoidance of puddling by the action of the irrigation water, that could perhaps be done as cheaply by appropriate systems of mulching, as by means of the underground tubes. Practically, the difficulty is usually met by "cultivating" the land carefully, with the horse-hoe, at appropriate moments when the surface has become dry, and by abstaining from actually "flooding" the ground with large quantities of water let on all at once. In the best practice, it is said that the water is let upon the land in several small rills, between the rows of the crop, and allowed to flow through them gently for two or three days at a time, so that it may soak sideways into the crop-bearing soil until the land has become thoroughly drenched. Whenever possible, it would seem to be best to drain the land by means of tiles, and then to irrigate it either upon the surface, according to the usual method, or according to the newer plan.

"Over-Irrigation."

Inasmuch as the quantity of water which evaporates from land irrigated beneath the surface would usually be much smaller than the amount evaporated from a similar area irrigated on the surface, it follows that subterranean irrigation might lessen the bad effects of what is technically known as "over-irrigation," which is often very harmful in hot countries.

As is well known, there are some countries where not enough water falls as rain in the course of the year to leach out all the soluble saline matters which are formed in the soil by way of disintegration. Under these conditions, potash, soda, lime, and even magnesia, are fixed and held by the double silicates in the soil in preference to soda which is left unfixed in the form of soluble

salts (sulphate, chloride, carbonate, etc.), which tend to move downward at times when the soil is wet with rain, and upward during dry weather when moisture evaporates from the surface of the land. It often happens indeed that the amount of saline matter thus brought to the surface is so large that visible efflorescences or even saline crusts are formed. (See Chapter IV. of Volume I.)

Naturally enough the saline matters tend to accumulate in salt lakes, such as the Dead Sea, the Caspian Sea, and the Great Salt Lake of Utah, and in low grounds whither they are carried by the occasional rains, both by the water which percolates through the soil, and by that which flows over the surface of the land. It is manifest, for that matter, that any soil from which little or no water ever drains away, and from which water is continually evaporating, must sooner or later be brought to the condition of a desert, as is seen to be the case indeed in the saline and alkaline deserts and desert patches in Utah, California, Central Asia, and many other localities, where brooks have for ages run into the valleys and low-lying plains, there to dry up.

In such regions, irrigation has to be managed with care lest it should lead eventually to the accumulation in the soil of an injurious excess of saline matters. There are probably few river waters in the world so pure but that in the end they might cause an injurious accumulation of soluble salts in a soil from which they were allowed to evaporate continually and completely. In India, the bad effects of such "over-irrigation" have often been manifested most conspicuously.

In the words of Hilgard, "Irrigation without proper provision for drainage, has in the past in very many cases been the cause of the abandonment of lands once abundantly fruitful, which were supposed to be exhausted by culture, but in reality had simply become over-charged with injurious salts or alkali, from the ever-repeated evaporation of enormous quantities of water, the solid constituents of which, though naturally very small, had nevertheless been concentrated too strongly in the soil."

Of these harmful saline matters, carbonate of soda is much the most injurious to vegetation; it may not only hurt the tilth of the soil, but actually kill the crops. According to Hilgard, if there is more than 0.25 % of the soda-carbonate in a soil, seeds will be killed by it during their germination. During the wet season it is true that no great amount of harm may be done by a

small amount of the soluble alkali, but it is apt to accumulate at the surface of the soil when the rains have ceased, and to corrode the root-crowns of plants, and to cripple or finally kill the crop.

On irrigating in arid countries, soils which are somewhat, yet not too highly charged with saline matters, it might be supposed, a priori, that the irrigation water would leach the soil, and that all risk of trouble from the saline matters might henceforth be avoided. On the contrary, it has been found in actual practice that the accumulation of saline matters at or near the surface is increased by irrigation, and that when carbonate of soda is present, so much of it may accumulate at the surface that cultivation becomes impracticable. According to Hilgard, The reason of this apparent discrepancy is simply that the amount, as well as the distribution of the irrigation water, is different from that of the rainfall of humid regions. Usually, the amount of irrigation water used is less than the annual rainfall of humid climates; and, besides, it is used in great abundance for a short time, the object being to wet the soil just to the necessary depth and no more. The water thus used carries the alkali with it; but, as it does not reach the country drainage, it reascends when evaporation begins, and finally, in case the whole of the water should evaporate, the whole of the alkali will come to, or close to, the surface. But as irrigation in arid regions usually penetrates deeper than the rains, this fact implies that a larger amount of alkali is now carried to the surface than was the case before.

Worse than this, if a pervious soil and leaky irrigation-ditches gradually fill up the whole country with water from below, the entire amount of alkali salts previously existing in the dry soil-mass, perhaps to depths of 40 or 50 feet, is brought near the surface, and thus the bottom water becomes the source of an almost inexhaustible supply of alkali, which may render the further cultivation of the land impossible unless it be done away with.

It is obvious, however, that all these difficulties could be remedied by under-drainage. If the soil were sandy it would be easy to wash out the whole of the alkali from the earth above the drains by one somewhat prolonged flooding. In the case of a clayey soil it would be more difficult to remove the soluble salts, and they would be brought up from greater depths, and on these accounts tile-drains are all the more necessary. Since the bottom water would be held in check by the drains, no further supply of alka-

line salts would rise from below, even in case of an ascent of the irrigation water by "filling up." . . . But, since under-drainage is expensive, and excessive flooding would carry away much valuable plant-food, it is often preferable to employ less radical remedies, such as mulches to hinder evaporation from the surface of the soil, keeping the land covered and shaded with deep-rooted, leafy crops, or neutralization of the alkali by chemical agents.

"When the alkali is not very abundant, frequent and deep tillage may afford all the relief needed. For, inasmuch as the drainage is, in most cases, the result of an excessive accumulation at or near the surface, it is clear that frequent intermixture of the surface layers with the deeper portions of the soil may so dilute the injurious salts as to render them powerless for harm. Moreover, since a perfect tilth of the surface greatly diminishes evaporation, it tends to diminish, concurrently, the accumulation of the alkali near the surface." (Hilgard.)

Decrease of Irrigation in Central Europe.

It is a noteworthy fact that, in some parts of North-Central Europe, irrigation was more frequently practised formerly than it is now. One of the chief difficulties of the earlier farmers, in regions of light, gravelly soils, was to procure enough fodder to keep their cattle through the winter. Before the introduction of clover and of turnips, and the practice of sowing methodically the seeds of good kinds of grasses, natural meadows were thought to be indispensable, even in England; and to increase the crop of hay upon them, they were watered in the spring, in case the season was dry, and in the summer also, after the first mowing. But when regular upland hay-fields and clover-fields were established, and turnips were grown freely, to say nothing of the modern practice of buying concentrated foods, the need of water-meadows was less keenly felt, and many of them were abandoned. One reason for the change was, doubtless, that the hay from watered meadows is less highly esteemed than that from upland hay-fields. It sells for less money in open market, just as the hay from reclaimed bog-meadows does to-day. But this objection is really one of no great importance, since it has been learned that a very small addition of oil-cake, of gluten-meal, of bran or malt-sprouts, or perhaps even of corn-meal, will make the hay from watered meadows as good as that from uplands for feeding neat cattle.

In England it is said to be a matter of common observation

that sheep cannot safely be pastured on watered meadows, excepting in early spring. Both sheep and lambs prosper on such pasturage in the spring, but if they are turned in upon it in the summer or in autumn, or even if they are soiled with grass cut upon watered meadows, they are apt to suffer from the disease called rot. It is not improbable that this experience may have led some farmers to abandon their irrigation works. It is noteworthy that, on the salt marshes of Southern England, "Sheep fatten very fast, and are not tainted with the rot." (Marshall.) There is still another reason for giving up water-meadows as the country becomes populous, and as its agriculture improves, in that much low-lying good land is needed for growing roots and vegetables, i. e., crops which are more remunerative than grass.

Warping.

A method of fertilizing land, known in England as warping, has long been practised in Italy, where in the winter, in times of freshets, the muddy water of rivers and of irrigation-canals is led upon land for the purpose, not of wetting it, but of changing its character by means of sediment which the water deposits. Many waste and worthless tracts have been made fertile in this way, by throwing up a dike of earth 2 or 3 feet high around the land to be treated, and partitioning off the enclosed area into a number of compartments by means of smaller dikes or bars of earth, those most distant from the source of the muddy water being no higher than 4 or 5 inches. The incoming water, as it flows from one compartment to another, naturally soon deposits much of its burden of mud as it comes partially to rest. When a sufficient quantity of sediment has been deposited in the first division, say a layer a foot and a half deep, the muddy water is made to flow directly into the second compartment, and so on until the entire field has been covered with the mud.

Gasparin tells of farm-land on the River Durance, originally worth less than $100 the acre, which was valued at $560 the acre after having been improved in this way. In some instances, in Tuscany and in the Austrian province Carniola, low-lying bog-land has thus been fertilized, and built up to the extent of 5.5 or even 7.5 feet in the course of 10 or 12 years by methodically leading upon it muddy brook-water in times of freshet, and retaining the water upon the land by means of dikes until the suspended matters had been deposited from it.

History of Warping.

The practice of warping is said to have been brought to England from Italy in the Eighteenth Century. It has been applied there with success in some special localities, as upon the banks of the River Humber, where the land is low, and where the tide rises and falls sufficiently to admit of the establishment of embankments, and of gates and sluices, by means of which the muddy water may be brought upon the fields at high tide, and let out again when the tide is low.

When a field is thus flooded, the water is left at rest upon it until the solid matter which the water held in suspension has been deposited. Where warping is practised in the low-lying lands of Lincolnshire and Yorkshire, it often happens that a layer of mud as much as one-tenth of an inch in thickness is left from a single flowage. By repeating the flowings often enough, it is easy to obtain a layer of excellent soil several inches, or even several feet thick. In some of the English localities, there is no difficulty in covering the warped ground with a foot of sediment in a single season. Usually the land is covered from one to three feet thick with the warp deposit in one, two, or two and a half years. Generally, one such treatment is found to be sufficient; but sometimes the spongy peat sinks so much under the weight of the solid matter thus laid upon it, that the land needs to be warped anew after a few years.

On this continent, some thousands of acres of fertile farm-land have been reclaimed by the method of warping, at the Basin of Minas, an inlet leading from the Bay of Fundy. (Shaler.) In certain districts in France, also, muddy river-water has occasionally been led upon light land in the winter, or upon stony, sterile land, and held quiet by means of temporary dikes until the suspended matter has been deposited, whereby the soil is improved both as to its depth and its texture.

In England freshly warped land is commonly left to lie fallow for a year, in order that the deposit may be tempered by the action of the air. It is then seeded down to oats, with a mixture of clover and grass-seeds. The grass is pastured by sheep for two years, and then ploughed up for wheat or for oats. No manure is required for five or six years, but after the lapse of this time guano, oil-cake, and farmyard-manure give good results. Horse-beans and rape thrive on warped land, but barley and turnips are said not to answer so well because of the sliminess of the soil.

Warping and Irrigation overlap.

In one sense, the process of warping may be regarded as a mere exaggeration of what is sometimes seen in nature. Thus, the overflow of the river Nile is an instance of warping upon a stupendous scale, only that the Nile flows the land upon its banks only once a year, while in the artificial system the flowage may be repeated with every tide until finished. Much in the same way as in warping proper, so in many special cases of irrigation a part of the useful effect obtained may justly be attributed to the improvement of the mechanical condition of the land by the sedimentary matters. Even waters that appear to be perfectly clear may some times hold enough clay in suspension to produce, in time, an appreciable ameliorating effect upon sandy soils, and in the case of turbid waters this effect may be produced quickly.

It is to be noted, however, that, in irrigation proper, muddy waters are seldom or never put upon land where crops are growing. It is essential that neither plants nor soils on which plants are standing should be smeared and clogged with silt or slime. It is only in the winter or the spring or autumn that the deposition of sediment is permitted. It is true enough that the waters of most large rivers are esteemed to be particularly fertilizing because of the loamy and vegetable matters which they hold in suspension, and that even a considerable degree of muddiness may sometimes be beneficial, as, for example, when bottom lands are overflowed in times of freshet in early spring or late in the autumn. When not in excess, the suspended matters will do no harm, but good, if only they are deposited before or after the growing season. It is notorious that there are many regions where flood-water which has come down from districts of chalky or calcareous soils are esteemed to be specially beneficial to grass because of the fertilizing matters they deposit, provided the water does not remain too long upon the land.

Usually the water of freshets is thought to do good to meadows when the water comes and goes quickly, and is not left lying long enough upon the land to spoil the grass, and many muddy waters are highly esteemed for autumnal irrigation. But it is a tenet of practice that during the growing season the water used for irrigating grass-land should be clear and free from suspended matters. In very many cases, muddy waters, or those holding solid matters in suspension, would have to be settled before they could

be usefully applied for irrigating growing crops. It often happens, indeed, particularly in mountainous regions, that instead of promoting fertility, the matters held in suspension by flood-water may do more harm than good, — as when a quantity of gritty silicious particles are brought down and deposited upon the blades of growing grass.

Warping and Irrigating in Egypt.

The difference between muddy and clear waters is well shown in Egyptian practice. From time immemorial, the agriculture of that country has depended primarily on the annual overflow of the Nile, which culminates towards the end of September. By means of cross-dikes, the turbid flood-water is held upon the land during 6 or 7 weeks, so that the soil is drenched thoroughly and its surface covered with a thick coating of fertilizing mud, on which the seed is strewn as soon as the water has been drawn off. Great crops of wheat, barley, beans and other pulse, and of clover, lupines, etc., are harvested in the course of the next spring. The land is then left bare until after the next inundation, so that a good part of the country lies idle during nearly half the year. As regards the crops above-mentioned, and the maintenance of the fertility of the soil on which they are grown, the deposit of mud is of paramount importance. But for the growth of summer crops, such as doura, maize, and onions, and particularly for cotton and the sugar-cane, artificial and continuous irrigation are necessary. Moreover, land devoted to cotton and sugar-cane must be kept free from the muddiness of the flood-water. Hence the application of irrigation pure and simple to these crops, without warping the land; and the use of artificial fertilizers, also, to keep up the fertility of the soil.

From Brackish Water Warp settles readily.

In England, warping is so much esteemed that the muddy water has in some instances been conveyed through channels to a distance of several miles before it is permitted to flow over the surface of the land. The process is said to be most beneficial on sandy and peaty soils. By means of it, large tracts of worthless land have been brought under profitable cultivation.

The completeness with which the suspended matter is deposited sometimes from the muddy water, when once it has come to rest, is remarkable. The fact depends, doubtless, on the presence of some sea-water in the muddy liquor, whereby the suspended particles

are flocculated. The English chemist Herapath observed, in one instance, that a water which contained 234 grains of suspended matter to the gallon deposited 210 grains during the process of warping. Although this water was less muddy than many specimens, it was computed that the land must have received from it more than three and three-quarters long tons of dry warp per acre for every foot in depth of water that flooded it. The deposited matter is of course extremely fine, and well fitted for the support of plants after it has become mixed with the coarser sand or peat of the land upon which it is deposited.

Between this system of warping, taken in the extreme English sense, where the water acts merely as a vehicle for bringing in and distributing a great quantity of solid matter, and that variety of irrigation which consists in flowing a grass-field, or a cranberry meadow, or a rice-field, with water, considered merely as water, there is of course every conceivable degree of variation as regards the clearness of the water. It is to be remarked, however, that the benefits derivable from warp will be chiefly felt by crops grown subsequent to the deposition of it; and this statement is essentially true, no matter whether much or little of the sedimentary matter is put upon the land.

Flooding of Meadows.

The occasional flooding of grass-land by backing up water upon it is a common method of irrigation in Germany, especially in situations where the water supply is precarious or inconstant. In this system the water is left to stand at rest on the grass-land for a longer or shorter interval, and is then drawn off completely. The fertilizing effects of the water may depend mainly, if not entirely, in this case, upon the matters dissolved in it which are retained by the soil, though it happens of course sometimes that substances held suspended by the water may serve a useful purpose in case they come to the land at times and seasons when no harm can be done to the growing crop. This method of flooding or inundating is held in far less esteem than that in which living water is made to trickle over the land; and it is evident that water which moves across a field in a thin sheet or layer, and continually brings to the land new quantities of fertilizing matters, as well as air, must usually be better than water left simply to stand upon the land. Indeed, such water would be apt to do harm by becoming stagnant if it were left to stand too long.

It is worth noting, nevertheless, that, in flooding a meadow, all the moles and mice and worms and insects which happen to be there will be destroyed and put out of the way of doing harm. Some kinds of useful plants will be killed also, but so will many kinds of weeds. It is easy to introduce good grasses, however, on flowed land, if only time enough be allowed, especially if pains are taken to encourage the desired kinds. It is to be observed, also, that one year's irrigation of a natural field may amount to nothing, because the grasses upon it may not be of kinds that profit by the wetting. In irrigating grass-land, botanical considerations are of equal importance with those which are purely chemical or mechanical.

The intervale or bottom lands of rivers are irrigated naturally by way of flowage, and it often happens that the process is allied to that of warping, inasmuch as some useful sediment is left upon the land in addition to the matters which the soil or the plants upon it may absorb from the water. It must not be forgotten, however, that the crops upon these intervale lands profit also from the underground water, which even in the driest seasons stands at a convenient height in them, not very far from the surface of the land. As has been said already, one advantage may be gained by flooding meadows early in the spring, in that the grass will begin to grow upon them earlier than it would have done otherwise.

In the rice-fields of many countries, the process of flowing is often dependent upon the ebb and flow of the tide in the river from which water is derived, and at certain seasons, when the water is turbid, the process becomes one of warping more or less clearly defined. In the Italian rice-fields, on the contrary, and those of Central India also, the ground is divided into compartments which rise one above the other in gradual succession up to the level of the canal from which the supply of water is drawn. The water that has been used to flow one flat is drawn off to flow the flat next below, and so on in succession to the lowest part of the field. In the case of this swamp-plant, the main object is to give it a thorough wetting, rather than to fertilize it by means of matters which the water holds dissolved, as is the case in ordinary irrigation.

Fixation of Matter from Irrigation Water.

An interesting illustration of the power of silicates and humates in the soil to fix several of the constituents of brook-water, and

of the significance of this fact as a means of explaining certain observed phenomena which were formerly incomprehensible, is afforded by the following statement of the distinguished French chemist, Malaguti. It is not very many years since he wrote as follows: —

"It has been noticed in England that water which had been used to irrigate a meadow lost the half of its chloride of sodium and of its bicarbonate of lime. This observation is exceedingly curious, for it reveals a mode of action on the part of the irrigating water that was far from being suspected. It was conceivable that the water with which a field was wet would be absorbed by the roots of the plants, and that it would give up to the plants the substances which it held in solution. It is conceivable, also, that the carbonate of lime held dissolved in the water by virtue of carbonic-acid gas would be deposited in part as the gas exhaled. But it is less easy to comprehend how the water, in passing over the field, can be deprived of a part of its common salt. It looks, indeed, as if plants were capable, under certain conditions, of absorbing a much larger proportion of saline matters than has been believed hitherto. But the fact, as above stated, explains perfectly why the waters used for irrigation lose their fertilizing power in proportion as their use is prolonged. Practical men express this fact by saying that the water is 'used up,' or that it is 'tired.'"

It is now known, of course, that, thanks to the reactions of the double silicates and humates contained in it, a soil may withdraw potash, magnesia, ammonia, and phosphoric acid from brook-water, i. e. precisely those substances which are most needed as food for plants; and that soda and lime may be absorbed also, as in the experiment cited by Malaguti, while they act to set free potash or some other fertilizing matter that had previously been fixed.

Moreover, the inability of the soil to retain nitrates explains how it is that water which has flowed over rich ground may be doubly valuable, in so far as this particular constituent is concerned, for the irrigation of poor land. It is known, too, that water which has been freely exposed to the atmosphere contains a certain definite amount of air, and that this air in water is much richer in oxygen than atmospheric air is. It contains, in fact, 35 % of oxygen by volume, and 65 % of nitrogen. Even the

air in rain-water and in melted snow has the composition here stated. Rain-water often contains, moreover, noticeable quantities of peroxide of hydrogen. But within the soil, the oxygen carried thither by water will quickly unite with oxidizable matters and be consumed. It follows that such introduction of oxygen dissolved in water is to be classed among the causes which work to make irrigation useful.

Waters that are fit for Use.

In view of the varying composition of natural waters, it is inevitable that the value of different kinds of water, considered as fertilizing agents, must vary exceedingly, according to the kinds and amounts of matter which the waters hold dissolved. A good example of such variation is afforded by the experiments of Birner and Lucanus on growing oats, by way of water-culture, in brook- and well-water. Among other things, 100,000 parts of the waters in question contained: —

	Nitrogen as Ammonia.	Nitrogen as Nitric Acid.	Phosph. Acid.	Potash.	Lime.	Sulph. Acid.	Magnesia.
The well-water . .	0.08	1.56	0.16	2.13	15.14	7.45	1.54
The brook-water .	0.08	0.04	0.11	0.62	7.84	1.46	0.87

The jars in which the plants were grown were recharged with water every week, one litre of water being thus supplied to each plant. An average plant weighed, dry, in the case of the well-water, 2.9190 grm. with 1.2490 grm. of grain; in that of the brook-water, 0.3112 grm. with 0.1087 grm. of grain. That is to say, the development of the plants was more vigorous in the well- than in the brook-water, in consonance with the larger amount of plant-food in the well-water. It has indeed always been recognized by practical men in all parts of the world, that, while the waters of some streams are peculiarly well fitted for irrigating, those of other streams are less valuable, or even wellnigh worthless. Dark-colored peat-water, for example, is considered to be wholly unfit for use upon irrigated meadows, unless, indeed, the soil of the meadow is calcareous; so, too, is stagnant water, such as has stood without movement in bogs. In general, any water which is not fully charged with air would be held in small esteem.

Chevandier and Salvétat, in a valley of the Vosges, irrigated one plot of meadow freely with water from a "bad" brook, and another plot with an equal quantity of water from a "good" brook. They obtained, per English acre, the following crops: —

Hay, bad brook	1,571 lb.	Good brook	6,484 lb.
Rowen, bad brook	847 "	Good brook	2,572 "
Total	2,418 "		9,056 "

No marked differences were found between the two waters in respect to their ash-ingredients, but the organic matter brought by the good water was more highly nitrogenized than that brought by the bad water. It contained, namely, 5.73 % of nitrogen against 2.38 % in the organic matter of the bad water; and the nitrogen of the good water was doubtless of better quality than that in the bad water. It may be said, indeed, that the research goes to show that the good water contained an extract of mild humus, and the bad water an extract of sour humus. It is probable, moreover, that the two waters carried different kinds of micro-organisms, in accordance with the differences between the organic matters. Many years ago, Gasparin remarked that warm waters used for irrigation are apt to contain highly nitrogenized confervae.

In cases where there is a choice between several streams, analysis would quickly show which is the best. There are various natural signs, also, that are dwelt upon by agricultural writers. Thus, when a brook is well stocked with aquatic plants, and when the stones at its bottom are covered with slime (so called), which is in reality a vegetable growth, and when the plants upon the banks of the brook grow luxuriantly, it may safely be concluded that the water is fit to be used for irrigating, since it must manifestly contain a good supply of the substances necessary for the growth of plants.

Naturally enough, the water should not be too cold. According to Caird, "In those irrigation canals (in India) which are fed from the melted snows of the Himalayas, the water comes down at a temperature much below that of the land to which it is applied. . . . The effect of this pure cold water on vegetation is only permanently useful when the land is sufficiently manured, and becomes positively hurtful when lavishly applied, year after year, to unmanured land. Irrigation from wells on each man's land [in this locality] is not open to this objection, as the water is used with economy, and only upon manured land."

In Europe, the water of wells is held in little esteem by irrigators — unless the well is situated in a calcareous soil — for the reason, as they say, that well-water is apt to be cold and hard,

and to favor the growth of inferior kinds of grasses. In Switzerland, it is an article of faith among irrigators that, when streams are swollen by the melting of the winter's snow, the water loses its efficacy, though when the same streams are swollen by rain in summer the water is excellent.

Other points to be mentioned are the influence which may be exerted by water, and carbonic acid in the water, to disintegrate fragments of rocks and minerals in the soil, and the tendency of moisture when in presence of air to cause humus to decay with improvement of its inert nitrogen. Evidently, in every system of intermittent irrigation, there must be times and seasons when the amount of moisture in the soil will be favorable for processes of fermentation, disintegration, or nitrification, as the case may be.

Irrigation with Liquid Manure.

A few words may here be said concerning an English method of applying liquid manure, which excited much attention some years ago. This method was suggested by the old Flemish practice of watering crops with liquid night-soil. It is said that even growing crops are thus watered in Flanders without harm, excepting in times of drought. The English idea was, instead of trying to absorb the liquid part of animal excrements with straw, or leaves, or peat, as is usual, to collect the dung-liquor in a cistern, and even to stir up the solid dung with water, and to send the fluid to the fields through iron pipes, there to apply it by way of irrigation.

The pipes were laid down as for an ordinary aqueduct, and the diluted manure was made to flow through them to the field under such a head of pressure that it could be thrown at will upon any part of the land by means of hose attached to hydrants on the pipe. When possible, the pressure necessary to discharge the liquid in this way was got by force of gravitation, i. e. the field to be irrigated was chosen at a level considerably lower than that of the barnyard. But since this method would only be practicable on a hilly farm, several persons who adopted the system did not hesitate to set up steam-pumps to drive the liquid through the pipes. Among others, Mr. Mechi, at Tiptree Hall, near London, employed steam in this way, and continued to use it until the time of his death, in 1880, while insisting that the method was a profitable one. His estate had come, however, to be a sort of show to be visited by agricultural travellers. In this case, the cattle were

kept upon a grating, through which their excrements fell into a tank of water. Sometimes rape-seed-cake was thrown into the tank, as in Flanders, or some other fertilizing material was employed to increase the value of the liquor.

In any event, the excrements were largely diluted with water before the liquid was sent out through the pipes, and it was even found to be well to give the land a dressing of plain water a few days after the application of the diluted manure. One rule was to water the land often enough to prevent it from becoming dry and parched, especially before the grass or other crop had grown tall enough to shield the surface soil from sun and wind.

Some farmers held that much larger quantities of water could be applied with profit than were actually needed for diluting and conveying the manure. They urged that a good soaking with an inch of water, equal to 100 tons to the acre, would amply repay the cost. But if this plan were carried out during the entire season, to the extent of 4 or 5 such drenchings, in addition to the liquid manure, a large supply of water would be needed.

Instances have been reported in England where grass was burnt and destroyed by applying liquid manure to it in hot, dry weather, though on the same farms similar quantities of the manure were very beneficial when applied during wet weather. Hence in places where there are no conveniences for diluting the liquid, the rule should be to apply it only in dripping weather. When it can be adequately diluted, the best service will naturally be got from it in warm weather. An analysis of the liquid manure used by Mr. Mechi will be found in Vol. II.

In a climate so mild as that of England, it might be possible in this way to apply all the manure to the land in the fresh condition, and so avoid the waste of nitrogen, which is inevitable when masses of dung, and especially urine, are allowed to accumulate and undergo destructive fermentation.

In cases where large numbers of cows are maintained upon watery food, such as green-cut clover or distillery slop, and where, consequently, much liquid manure is produced naturally, it might be specially advantageous to send this product immediately to the fields as a means of saving it. Such masses of liquid manure are notoriously difficult to manage. They are not readily to be stored, and the material is one specially apt to run to waste, and to spoil rapidly when kept. Some years ago, a German writer called at-

tention to the fact that the most favorable condition for adopting this system of irrigation would be a milk farm based on potato slop, roots, and green fodder. For, in this case, a large proportion of the manure will be produced in the liquid form, and no straw will be at hand to absorb the liquid. The crops, moreover, are of kinds that will bear forcing.

Many large-way farmers in Europe, recognizing the great value of liquid manure and the impossibility of keeping it, are accustomed to distribute some of it, properly diluted, upon grass-land, or to help forward a backward grain-crop in the earlier stages of its growth. For this purpose, the liquid is carried out in great casks set upon wheels, similar to the watering-carts employed to lay the dust in cities. Sometimes it is used also, as in Flanders, to force gross-feeding crops, like tobacco or cabbages.

Failure of the Pipe System.

After thorough trial, continued in several instances through a long series of years, the elaborate English experiments have been given up, and the idea of manuring a whole farm in this way, or anything more than some favorably situated field, is now esteemed to be an impracticable notion.

The trouble lies in the original cost of establishing the system of pipes and the pumping apparatus. Many years ago, Voelcker contrasted the cost of distributing the liquid manure at Mr. Mechi's farm with that of applying an equivalent quantity of guano, as follows. About 50,000 gallons of liquid were applied to the acre, at a cost of 4 cents per ton. This quantity of the liquid contained about 39 lb. of ammonia, or as much, perhaps, as 2 cwt. of guano. But with guano at $65 the ton, 2 cwt. of this fertilizer would cost less than $7, while the 50,000 gallons of liquid manure (= 500,000 lb.) cost more than $9.

The liquid manure was not found to be so generally applicable as guano, in the English practice. It answered an excellent purpose, however, upon grass, — particularly upon Italian ray-grass, — and did tolerably well with the other forage crops. In dry seasons, especially, the crops succeeded admirably, — the very years, of course, when the products are most valuable. So, too, in early spring an abundant growth of grass could be started at the time when the winter's store of turnips and other food was beginning to be exhausted.

The following statement applies to a farm in Scotland, near Ayr.

On poor, sandy soil, Italian ray-grass was sown in the autumn and brushed in, at the rate of 4 bushels to the acre. The land was then watered and left until the next spring, when the grass was mown in June, and yielded 10 or 12 tons to the acre. After this first cutting, a mixture of guano and sulphate of ammonia was strewn upon the land, at the rate of 3 or 4 cwt. to the acre, and was washed in with 100 tons of dilute liquid manure that was delivered through pipes. In 5 weeks the grass was 3 feet high, and, on being mown, yielded 16 to 20 tons to the acre.

The land was again manured as before, and yielded 16 to 18 tons of grass early in September, and a further manuring gave another crop of 10 or 12 tons towards the end of October. In the spring, another dressing of the water gave a cutting of grass towards May, and second and third cuttings were had, amounting to 40 or 50 tons of grass by the end of August. During two years, the land is said to have yielded between 80 and 100 tons of green food per acre in 7 cuttings, by the use of 1 ton of guano, sulphate of ammonia and nitrate of soda washed in with 700 tons of the weak liquid manure.

It was upon Italian ray-grass, indeed, that the use of liquid manure in England chiefly depended, and farmers there were at one time much attracted by the idea of growing a crop which — unlike the root-crops to which they were accustomed — should, without need of cultivation or of constant resowing, give a regular supply of highly nutritious food, for stock, that required no hay or straw or other food to be given along with it. The ray-grass was kept down for two years, during which period it was mown 10 or 12 times, and after each cutting the land received from 3,000 to 20,000 gallons of liquid manure to the acre.

The quantity of water to be mixed with the manure was determined by the dryness of the soil and of the weather. At a wet time, 5,000 gallons of undiluted liquid-manure might be applied, but if the soil was parched, and there was no prospect of rain, water enough was added to make the dressing equal to 23,000 gallons to the acre, which would be equal to an inch of water or to ten hours of rain. When the land was broken up, after the two years of ray-grass, it was found to be perfectly clean, and grain could be grown upon it without applying any manure. Indeed, the soil was rather too rich at first for grain, except oats, which are less liable than wheat or barley to be injured by over-luxuriance. After the oats, wheat gave heavy crops of good quality. Clover was sown with the wheat and dressed with dung, and grain and roots followed it, as in ordinary English farm practice, before returning to the irrigated ray-grass.

Liquid Manure on Grain.

When applied directly to grain it is characteristic of sewage irrigation that it causes plants to run to leaf. But while leaves are developed by it in abundance, it tends to retard the ripening of grain and of fruits. In respect to grain, there is the same difficulty that has been mentioned under the head of nitrates, viz.;

that, when once the grain-crop has begun to ripen, it must not receive new supplies of nitrogenous food, lest the formation of new leaves and shoots should be encouraged, and the filling out of the ears be hindered.

On some sewage farms in England "the sewaging for grain-crops is confined to a winter irrigation of the land intended for spring-sown crops, and a watering in early autumn, if the weather permits, of the land that is to receive a wheat-sowing." One great trouble is that comparatively few field-crops can be forced much without risk of lodging.

As has been said already, it has long been customary, in ordinary farming, to use dung by preference upon certain preparatory crops, and not to apply fresh, rank manure to grain, lest the plants should run to leaf; and it is for the same reason that liquid manure is not well adapted for grain. It is an old rule that, in order to guard against the lodging of grain, manure should be applied and be well worked into the soil some time before the seed is to be sown; and that, in case a top-dressing is to be applied to grain, the dressing should be a light one. But it is not easy to manage liquid manure so that either of these acts may be properly performed. Even rape and Italian ray-grass, which will bear much forcing, must not be manured too strongly, lest they lodge, and impede the scythe, or even rot upon the ground.

There are, however, among agricultural plants, a few "gross feeders" which seldom or never lodge, no matter how highly they are manured. Cabbages, beets, tobacco, hemp, Indian corn and sorghum, for example, will stand almost any amount of forcing. It is said that hemp has approved itself particularly on fields irrigated with sewage at Berlin, and that better economic results have been got there by means of this crop than by almost any other.

Soils fit for Liquid Manure.

From the first, it was recognized in England that liquid manure cannot be applied with advantage to all kinds of soils. It is not at all fitted, for example, for use upon heavy clays, for it "cakes the ground, seals up its pores, and prevents air from getting at the roots of the crops." But, as regards clayey loams, it is not impossible that some of them might be irrigated freely, after their excessive plasticity had been corrected by applications of lime. Even peat or bog-earth, which has been thoroughly drained, and

has once become mellow by slow fermentation, admits of being watered freely whenever moisture is needed.

But it may be laid down as a general rule that experience has taught that liquid manure produces the most beneficial and the most striking effects when applied to light, deep, sandy soils, resting upon porous subsoils. However poor such soils may be originally, repeated applications of liquid manure render them capable of bearing remunerative and even large crops. This result is seen most conspicuously in Flanders, where astonishing changes have been brought about upon almost sterile lands by the use of liquid manures. One reason why liquids succeed so well upon sands is that the constituents of the manure can penetrate such soils deeply and uniformly; and, as has been said already, — provided food and moisture are at hand, — the porosity of sand is advantageous, in that it permits the roots of plants to move about freely in all directions, and to acquire a perfect development.

Evidently a modification of the English system might sometimes be adopted. Thus, in case there was only a moderate fall between the barnyard and the field to be irrigated, the liquid manure might still be made to flow by force of gravity into a tank in the field, whence it could be thrown about in all directions by means of a force-pump or a garden-engine, or it might be distributed with buckets. For an arrangement such as this cheap V-shaped wooden gutters might be substituted for the iron pipes, in some localities.

It is conceivable that, with inexpensive apparatus such as this, it may sometimes be advantageous to set apart a single field to receive the excess of liquid manure from the barnyard and the kitchen sink in cases where tobacco can be grown, or merchantable vegetables, or perhaps even in cases where fodder-corn could be forced for feeding cows. Many a small sloping field might be well manured by occasionally pumping, with steam or horse power, the contents of a barnyard cistern into an open ditch or ditches running across the field. Either this work would be done at a time of rain, or the original liquid manure would be diluted with much water, as in all such cases of flowage. The diluted dung-liquor of the English plan was a very different and a much weaker product than barnyard liquor or than urine.

A remarkable mixed system of manuring and watering has been practised in Belgium in a sandy region known as the Campine. The system consisted in irrigating the barren grass-land with canal-

water during the autumn, and again in the spring until April, when the grass was gone over with a stiff brush harrow, and a dressing of 100 lb. of guano to the acre was applied to it. After the application of the guano, the supply of water is shut off for a fortnight, and subsequently the water is only let on occasionally during the growth of the grass, i. e. as often as the ground becomes somewhat dry. Since the ground lies low, and is full of ditches, there is no need of frequent irrigation. After the grass has been mown, another dressing of 25 lb. guano to the acre is applied.

CHAPTER XXXIII.

SEWAGE.

The question how best to dispose of the sewage of cities is one of great general interest and importance, concerning which much might be said. Indeed, few questions relating to agriculture have been more frequently discussed in recent years than this one, and upon none have discordant views been urged more emphatically.

It has become customary and fashionable for magazine writers to bewail the wasteful habits of civilized men and to lament the vast quantities of fertilizing materials which, as they say, are unnecessarily lost to agriculture when sewers are made to flow into the sea; and a great variety of people have joined in this cry, from Baron Liebig in the scientific journals to Victor Hugo in his novels. The matter has been discussed from many points of view, moreover. To some minds the question presents itself as one of conscience or morality, for others it is a question of political economy, while to many persons it is a matter of sentiment pure and simple. Few, if any, practical farmers have been able to perceive that the question has any general or important bearing upon agriculture.

In reality, the problem how to dispose of the sewage of a city is simply a sanitary question. First and last, the subject relates to the health and comfort of the citizens; and it needs to be clearly understood that neither agriculture nor political economy has any concern as to what shall be done with the filth of cities, until all sanitary requirements have been fulfilled, effectively and economically.

A single sentence, quoted almost at random, will show the general drift of the sentimental feeling just now referred to. It was

written some years since, as expressing the views of the famous German chemist Liebig, whose eloquence and enthusiasm often enough carried him far beyond the bounds of sense and sobriety.

"England," he exclaims, "is robbing all other countries of the conditions of their fertility. Already, in her eagerness for bones, she has turned up the battle-fields of Leipsic, of Waterloo, and of the Crimea; already from the catacombs of Sicily she has carried away the skeletons of many generations of men. Annually she removes from the shores of other countries to her own the manurial equivalent of three millions and a half of men; she takes from us the means of supporting them, and squanders it down her sewers to the sea. Like a vampire she hangs upon the neck of Europe,—nay, of the entire world,—and sucks the heart-blood from nations, without a thought of justice toward them,—without a shadow of lasting advantage to herself."

"It is impossible," he goes on to say, "that such iniquitous interference with the Divine order of the world should escape its rightful punishment; and this may, perhaps, overtake England even sooner than the countries she robs. Most assuredly a time awaits her when all her riches of gold, iron and coal will be inadequate to buy back a thousandth part of the conditions of life which for centuries she has wantonly squandered away."

Considered as a mere matter of reasoning, the fallacy of such talk as this can easily be shown; but the feeling or sentiment which the citation illustrates is endowed with perennial vigor, and probably it can never be composed.

It is true, no doubt, that, as a result of the circulation of phosphoric acid, of potash, of nitrogen, lime, etc., out of the earth through plants and animals to man, enormous quantities of these matters do go to waste under the existing conditions of civilized life, particularly wherever large numbers of men are congregated. It is true, moreover, that it is easy to conceive of a closed and close circuit, as it were, in which these elements of plant-food should be returned from man directly to the soil whence they were originally derived; and there is seen, in fact, in China, Japan, and Belgium, a tolerably close realization in practice of this theoretical conception. But, to say nothing for the moment of the enormous risks to health which may lurk in human excrements, it is also true that every farmer, in these days of safe and easy communication, at least every farmer who lives within the limit of influence of a great city, or within reach of railways or steamboats, has the whole world from which to draw his supplies of manure. He can get the phosphoric acid needed by his crops from the deposits of phosphate-rock in South Carolina, Florida, and the Carib-

bean Sea, or from certain slags obtained in the manufacture of steel, or from the coprolite beds of England, Belgium, Germany and France, or from the mines of apatite in Canada and Spain, and several other localities. Nitrogen he can have in abundance from the gas-works of cities and from coke furnaces, from the nitre-beds of Peru, and from the refuse of fish, flesh, and oily seeds; while of potash there is an inexhaustible store at Stassfurt.

Commercial Fertilizers better than Sewage.

So long as the supply of artificial fertilizers remains abundant, the farmer is virtually independent of the sewage of his city. Indeed, he cannot afford to think of using the sewage, unless it can be supplied to him at less cost of money and labor than would suffice to bring to him a corresponding supply of fertilizers from abroad. Another point to be particularly noticed is that, in so far as general agriculture is concerned, the question of using sewage is necessarily of slight interest, because the available supplies of sewage are extremely small in comparison with the area of land in the world which has got to be manured. It has been computed, for example (in 1876), that the whole amount of land which the sewage of Paris could effectually fertilize does not exceed 12,000 acres, and that the produce of this land, enhanced though it might be under the influence of such manuring, would barely provide food for one-fifth of the population of the city.

Weakness of Sewage.

A ton of sewage, such as is produced in European cities that are provided with aqueducts and water-closets, ordinarily contains some 2 or 3 lb. of total dry matter. In American cities, the amount of dry matter in sewage is still lower. W. R. Nichols found less than 2 lb. of it to more than 1,998 lb. of water in Boston sewage in 1872; and about 1 lb. to the ton in the sewage of Worcester, Massachusetts.

With regard to the variations which may occur in sewage from week to week, accordingly as the weather is or is not rainy, Lawes and Gilbert have made the following statement of the highest and lowest number of pounds (avoirdupois) of total dry matter found in the long ton of Rugby sewage: —

	24 Tests, April, 1861, to Nov., 1861.	34 Tests, Nov., 1861, to Oct., 1862.	35 Tests, Nov., 1862, to Oct., 1863.
Largest amount	6.93	4.14	8.64
Smallest amount	1.20	1.62	1.99
Means	2.41	2.57	3.30

The amount of matter actually in solution in the Rugby sewage, and of that in suspension also, will appear from the following table, which gives the mean results of all the (93) analyses above mentioned, in pounds (avoirdupois), in a long ton of English sewage: —

	Dissolved Matter.	Suspended Matter.	Total Dry Matter.
Organic	0.276	0.603	0.879
Inorganic	1.146	0.778	1.924
Sum	1.422	1.381	2.803
In 2,000 lb. Boston sewage . .	1.179	0.747	1.926
In 2,000 lb. Worcester sewage .	0.507	0.423	0.930
In 2,000 lb. Berlin sewage . . .	1.578	0.102	1.680
In 2,000 lb. Dantzic sewage . .	1.366	1.164	2.530
In 2,000 lb. of sewage, average of 50 English towns	1.444	0.894	2.338

Of the fertilizing matters in sewage, the nitrogen compounds are by far the most important, but the amount of them is very small. More or less of the nitrogen will naturally be in the form of urea, or of ammonia, according as the sewage is fresh or old. In any event, a considerable part of the nitrogen will always be in the form of inert organic compounds other than urea.

Letheby gives the average amount of nitrogen in the sewage of English towns as 0.178 lb. to the ton. Lawes and Gilbert have noted that the average of many analyses of London sewage gives 0.206 lb. of ammonia to the ton; as the mean of 93 analyses of Rugby sewage, they found 0.185 lb. of ammonia to the ton. The average of 50 English towns is said to be 0.155 lb. of total nitrogen to the ton of sewage. In this case ammonia was given as 0.134 lb., and 0.044 lb. of the nitrogen was said to be in organic combination. Traces of nitrates are commonly observed.

The sewage of Dantzic, in Germany, is said to carry 0.13 lb. of total nitrogen to the ton, 0.023 being in organic combination. The amount of ammonia is stated as 0.129 lb. to the ton. In Boston and Worcester sewage Nichols found 0.054 lb. and 0.038 lb. of ammonia, respectively, beside traces of nitrates.

As for phosphoric acid, 0.034, 0.032, 0.007, and 0.003 lb. of it to the ton of sewage has been found in Boston, Berlin, Worcester, and Dantzic, respectively. Letheby puts it as high as 0.045 lb. for the average of English towns; and potash he rates at 0.048 lb. to the ton of sewage.

From data such as these it has been estimated that the sewage of English cities may contain in every ton from 1 to 4 cents' worth of fertilizing matters.

A ton of the Boston sewage above mentioned may perhaps have contained a cent's worth of plant-food; or, speaking more precisely, 400,000 parts of this sewage contained some 11 parts of ammonia and nitrates, which is about as much as would be contained in 100 lb. of really good Peruvian guano, and less than 7 parts of phosphoric acid, or little more than half as much as the 100 lb. of guano would contain. Since the sewers of a city carry off vast quantities of rain-water, as well as all the water that is delivered by house-drains, it is evident that in regions where the rainfall is large, as well as in cities that are abundantly supplied with aqueduct water, the sewage will be specially worthless.

In some American cities the average consumption of water for each individual inhabitant amounts to 100 gallons or more daily; and, in so far as concerns the present argument, it is no matter that much of this water is "wasted," for practically a very large part of it goes into the sewers, to the great advantage of the public health, it should be said. Since the average rainfall and the average water-supply in American cities are about twice as large as in most English and German towns, American sewage will naturally be more dilute than that of Europe.

The economic Argument against Manuring with Sewage.

To illustrate the poverty of sewage in respect to fertilizing ingredients, it may be urged, as a self-evident proposition, that any man would be foolish if, wishing to apply lime to his fields, he should insist on doing so through the intervention of sewage, although sewage does contain a certain small proportion of lime compounds. In London, for example, Way found from 0.04 to 0.07 lb. of lime to the ton of sewage. In point of fact, when the farmer wants lime, as a source of plant-food, he buys it for a song in the shape of quicklime or of leached ashes, or in the form of waste lime from soap- or gas-works, or as gypsum even, and takes no further trouble. But in precisely the same way he can buy phosphoric acid and nitrogen and potash, as well as lime; and by the simplest rules of business he is bound to obtain these things wherever they can be had at the best advantage.

As was suggested long ago by Anderson, it would be about as reasonable to expect the farmers to manure their land with the

smoke of cities as with sewage; for, as every one knows, enormous quantities of ammonia must be lost in the aggregate from cities where domestic fires are fed with soft coal. But precisely as it is with smoke, so is it with sewage; that is to say, the fluid is so very dilute that it cannot be put to use. The geologist David Forbes also, in replying to calculations based upon the assumption that the excrements of each inhabitant of a city represent a value of several dollars a year, argued that it would be equally correct to maintain that a barrel of water into which a bottle of brandy had been poured would be worth as much as the original brandy. Most of the alcohol could indeed be recovered from the water by distillation, but at a cost far greater than its value; and so it has proved to be with sewage whenever attempts have been made to extract the fertilizing matters that are contained in it.

No matter how freely it may be admitted that immense quantities of plant-food are carried out from a city every year through the sewers, it remains none the less true that these fertilizing matters are carried out in a state of such extreme dilution that it is idle to talk of recovering any of them economically in the present conditions of labor and commerce, or of utilizing the sewage in any way excepting in arid regions and in some rare localities, as at Edinburgh and Milan, where circumstances permit of the foul water's being applied directly for purposes of irrigation.

Other Examples of Dilution.

There are many other familiar instances of valuable matters to be found at our very doors, so diluted that they are not worth the cost of collecting or saving. From the experiments of Eckfeldt and Dubois, of the United States Mint at Philadelphia, it appears that beneath the paved portion of that city there is an extensive bed of clay which contains a pound of gold for every 1,224,000 lb. of clay. In every cart-load of clay hauled out in excavating the cellars of Philadelphia there is concealed as much gold as would be sufficient to pay for the carting. If the bricks that front the houses in that city could have their contents of gold brought to the surface in the form of gold-leaf, there would be a glittering patch of two square inches upon every brick.

In that portion of the clay-bed that lies beneath the streets and houses of Philadelphia there are some 126 millions of dollars' worth of gold, and it is safe to assume that there are eight times as much

of the clay within the corporate limits of the city. But, excepting as a matter of scientific interest, no one has ever dreamed of extracting gold from the Philadelphia clay. It would be folly to think of extracting it so long as gold can be got with infinitely less trouble from places where it is more abundant. Of course here, as everywhere else, the cost of getting the thing depends on the amount of labor that must be expended; and in the present condition of things, labor can be expended to so much better advantage in ten thousand other ways that no one can afford to extract this gold.

Some old gold-washings on the river Rhine, and in Hungary also on the Drave, afford an analogous example. Certain gold-bearing sands occur there which carry so much gold that it is almost, but not quite, worth while to work for it in ordinary seasons. But in times when the price of labor has been exceptionally low, that is to say, when, from the partial failure of crops, there was unusually little work to be done, and there were more laborers in the region than could find occupation, it has happened that the unemployed men have turned their attention to gold-washing, and have in that way made shift to keep body and soul together. Something similar is seen at many exhausted gold-washings in California, where, in anticipation of special holidays, or the advent of some wandering show, the village boys are accustomed to wash out gold-dust enough from the waste gravel to enable them fully to enjoy the occasion.

There is no need, however, to go outside the domain of agriculture to seek for examples. So long as there is inert nitrogen in coal, from which ammònia might be had at no very great cost if we cared to èxtract it, it is idle to talk of the "irreparable" waste of nitrogen in sewage. Such talk was simply foolish so long as the gases distilled from coke furnaces were permitted to escape unchecked into the air, as they are indeed, even now, in many places. It is safe to say, for that matter, that when there is no more fish-scrap to be had from the sea, and that when the stock of nitrogen in peat and in bituminous shales is exhausted, then ammonia will be collected from many furnaces where coal is burned as fuel. Such sources of ammonia as these will undoubtedly take precedence of the nitrogen in sewage.

So, too, when the mine at Stassfurt shall, perchance, show signs of failing, there will still be, as before, unlimited supplies of pot-

ash in the granitic rocks which are found pretty generally diffused on the face of the earth; and it will undoubtedly be found more convenient then, as now, to extract potash from such rocks, than to get it out of sewage. It will undoubtedly be found still cheaper then, as now, to let plants get the potash out of the rocks, and then take it from the plants, as has been the custom hitherto.

Potash farming.

How was it with respect to potash formerly, before the discovery of the Stassfurt mine? Why, it was actually at one time an agricultural product; i. e. it was a crop, in the strictest sense of the word; and it is so still, perhaps, in some places, though the working of the Stassfurt mine, which upon the whole has been a great boon to agriculture, has interfered very decidedly with the tolerably large class of husbandmen who depended for their livelihood upon the making of potashes.

Wood is so abundant and unmerchantable in several thinly populated countries, as at the North of Europe, as well as in some parts of Canada and of our own country, that the only way of deriving profit from it was to burn it solely for the sake of the ashes. The same remark was true formerly of straw and weeds in some parts of Russia, and it was true also, at one time, of brushwood and the trimmings of logs in Germany, for potashes were a highly important product previous to the invention of an economic process for making soda-ash from common salt, and the substitution of this alkali for the more costly potash compound. In 1789, according to Marshall, great quantities of bean-haulm, as well as some straw, were bought up about Gloucester (England), at a potash manufactory, and burnt for the ashes.

There can be no question as to the propriety of the old custom of burning wood merely for the sake of its potash in those, comparatively speaking, inaccessible places which were unfit for the more profitable operations of agriculture. It is a simple question of getting an honest living as easily as possible. In some places cotton is the proper crop, in some wheat, in others corn, in some hay, and in others potash. This is all that can be said about it; and so long as potash can be had in this way more cheaply and conveniently than it can be had from human excrements, it is truly absurd to lament the sending of sewage potash to the sea. In the case of the forest wood the continual disintegration of the soil keeps up a sufficient supply of potash, so that the potash hus-

bandry now in question might be carried on for an indefinite period. The idea of completely exhausting a soil in this way is not to be entertained, since the supply of wood is practically unlimited, and the potash farmer must of necessity allow as much time as is required for the new wood to grow.

It has been calculated that a single cubic foot of feldspar is sufficient to supply an oak wood covering a surface of 26,910 square feet with potash for five years. As has been said before, it is customary in the vicinity of Boston to take repeated crops of hard wood from poor gravelly soils every 15, or 20, or 30 years, and there is not the least prospect of the soils becoming exhausted. There are, withal, several other large deposits of potash known in the world beside the one at Stassfurt, not to speak of numberless saline lakes. The Dead Sea, for example, is capable of supplying enormous quantities of potash salts, as well as of chloride of sodium.

Phosphates are not yet unduly Costly.

The risk that the present abundant supplies of phosphoric acid may give out is hardly any greater than the risk that nitrogen or potash may fail. Several important deposits of phosphates have been discovered in recent years, and large quantities of impure phosphates, not rich enough to be mined at present prices, are known to exist. Thirty or forty years ago greater uneasiness was felt in respect to the continuance of abundant supplies of phosphates than would now be justified. Indeed, the price of phosphoric acid, which rose decidedly shortly after the middle of this century, now tends to remain tolerably constant and moderate, in spite of the enormously increased use of phosphatic fertilizers.

The discovery of the rock phosphates of South Carolina and of Florida, and the apatite of Canada has manifestly had a very great influence in checking the rise in price of all kinds of phosphates, and so has the production of phosphatic slags in certain methods of steel-making. But it is to be remembered that deposits of rock phosphates are found not infrequently in France and Belgium, that they abound in Russia, and that enormous masses of phosphates occur in Spain. There are, in fact, many localities now more or less inaccessible from which phosphates might be obtained in case of need. Nowadays some small quantities of phosphates are recovered in the form of fish and flesh-scrap, and in wood-ashes, and it may perhaps be true that, if worst came to worst, merchant-

able supplies of phosphoric acid might be had from these things more conveniently than from sewage.

Meanwhile, it is a highly interesting fact, that at the South Carolina phosphate beds, even before the working of phosphate beds in Florida, the laborers dug no deeper than ten feet from the surface of the land. So long as the price obtainable for the mineral was no higher than it was even then it did not pay to dig for it any deeper than ten feet, unless the nodules happened to be of very superior quality. (Penrose.)

It is consoling to reflect, withal, that in case the supply of mineral phosphates should give out some day, and it should then be found impracticable to get enough phosphoric acid from fish and from sea and land plants, there would still be the city filth to fall back upon. For it is a peculiarity of the case, which some writers seem to have overlooked, that just as much of phosphoric acid and of the other fertilizers will be excreted in the future as now, so long as men are constituted as they are, and so long as they are as well fed. Whenever it shall be found advantageous to begin to save these matters, posterity will be in no single particular less favorably situated for doing so than we are now.

Manifestly, then, it is the part of wisdom to have the fertility of farms kept up by means of manures that have been obtained in the most economical manner possible, no matter whence these manures have been derived. It will be time enough to begin to utilize sewage and night-soil when circumstances shall indicate the economy of so doing. There is need, meanwhile, that every instructed person should do what he can towards discountenancing the absurd view that the sewage of cities "belongs" to the land. This idea has done infinite harm already, by hindering municipal authorities from establishing fit systems of sewerage, such as the health of the inhabitants demands. It would be well, withal, for every one to understand that, when the farmers really want the filth of cities, they will find means of getting it. They will speedily take measures for informing the citizens of their desires.

"Waste" of Fertilizers by Rivers.

There are other considerations beside those just now urged which go to show the absurdity of the cry that the great cities are wasting the fat of the earth through their sewers into the sea. Look at all the rivers in the world. What goes to waste through them? Consider the supply of phosphoric acid from which wild plants get

what they need. It comes, manifestly, from the decomposition of rocks by the action of water, air, carbonic acid, and other chemical agents. But beside going into plants, some part of these highly dilute solutions of phosphoric acid, and of the other elements of plant-food as well, are all the while slowly leaching out of the soil into the brooks and rivers, and so into the sea. The mere fact that aquatic plants grow in the waters shows the presence of phosphates there plainly enough.

It is true, of course, that the absorptive power of the soil works against the escape of phosphoric acid from the land, but it is powerless to prevent it entirely. This waste goes on incessantly by day and by night, as it has gone on since the beginning of time, and the aggregate amount of material thus transported by even a single one of the large rivers must be simply stupendous.

Perhaps there is more phosphoric acid thrown out in this way naturally into the sea in a single day than would be discharged in a century by all the sewers in the world. So, too, with nitrogen. Boussingault has shown that the rivers Rhine, Moselle, and Meuse may each discharge daily into the sea an amount of nitrates equal to 212 tons of saltpetre. The Seine, he says, carries out 260 tons every day, on the average. If the water of the Nile contains no more nitrates than that of the Rhine, some 330 tons of saltpetre would be discharged daily, on the average, by the African river. But if Barral's estimate of the proportion of nitrates in Nile water is correct, the quantity of saltpetre discharged every day by this river must be 1100 tons.

It needs no careful calculation to show that the amounts of phosphoric acid and of nitrates carried off artificially in the sewers must be wellnigh insignificant, in comparison with that which goes to sea naturally every hour, through rivers all over the globe. Precisely in the same sense that it would be foolish to try to collect these fertilizers from the river-water in cases where they could be had at less cost from sewage, so is it foolish to think of getting them from sewage when they can be got at still better advantage from fish and sea-plants, and from minerals taken from the earth.

Matters carried by Rivers.

Breitenlohner has made detailed observations as to the amounts of plant-food which are carried out of Bohemia every year in the water of the River Elbe. All the brooks and rivers of Bohemia

flow into the Elbe, and it was a comparatively easy matter to analyze the water of this river repeatedly, and to determine the rate and amount of its flow. The average rainfall was well known through observations made at 72 stations for rain-gauges in the country, and it had been shown, indeed, by the investigations of Harlacher, that about one-fourth of the yearly rainfall in Bohemia flowed out through the river. The other three-fourths either evaporate into the air in various ways, or soak out of the country as ground-water. Actually six billion cubic metres of water flow past the town of Lobositz in a year, and this water contains, in terms of millions of kilograms: —

	Ash-ingredients.	Expelled on ignition	Total.
Dissolved matters . . .	481.98	140.70	622.68
Suspended matters . .	495.72	51.42	547.14
Total	977.70	191.12	1169.82

Moreover, the six billion cubic metres of water contain the following amounts of agriculturally important ash-ingredients, stated in terms of millions of kilograms: —

	Suspended.	Dissolved.	Total.
Lime	2.98	137.40	140.38
Magnesia	1.73	26.40	28.13
Potash	24.34	30.18	54.52
Soda	5.46	34.14	39.60
Chloride of sodium . . .	. . .	25.32	25.32
Sulphuric acid	0.27	45.42	45.69
Phosphoric acid	1.50	trace	1.50
In sum	36.28	298.86	335.14

That is to say, 89 % of dissolved and 11 % of suspended matters. Since a kilogram is equal to 2.2 lb., it appears that of phosphoric acid alone more than 3 millions of pounds are carried off every year in the river-water.

Reade has computed that the Mississippi discharges annually 150,000,000 tons of solids in solution, while Russell puts the amount of mineral matters in solution at about 113,000,000 tons, in addition to the visible load of suspended silt, which is about 4 times as large as the quantity of dissolved matters. He estimates that the Mississippi carries into the sea daily 309,100 tons of inorganic matter in solution, and that 137,419 tons of it are carbonate of lime. The Hudson carries daily 4,000 tons of dissolved inorganic matter, of which 1,200 tons are carbonate of

lime; the Croton River, of New York, 183 tons of inorganic matters in solution, of which 47 tons are carbonate of lime. The Thames, in England, is said to carry daily 1,682 tons of soluble inorganic matter, of which 1,121 tons are carbonate of lime.

It is to be remembered, also, that in the same way that matters carried to the sea by rivers serve to feed marine organisms in infinite variety — and to support the fishes which are so important for human welfare — so will the constituents of sewage be put to use in the sea in a precisely similar way, and not be "lost." On the continent of Europe, where carp are "cultivated" methodically in ponds, horse-manure has often purposely been given to them as food, as well as a great variety of other kinds of refuse animal and vegetable matters.

Modern Improvements.

It is idle to assert, as has been done far too often, that the sewage of a city like London carries away every year several millions of dollars' worth of fertilizing materials, so long as the stubborn fact remains that very large amounts in terms of life also, as well as in terms of treasure, would have to be expended in order to collect the fertilizing matters, and bring them into forms available for agricultural use. From the sanitary point of view, nothing can be more important for the health of the citizens than that all excremental matters shall be sent out of town as speedily as may be possible. And the best means yet invented for accomplishing this purpose is to float them out in a great volume of water.

Instead of the stagnant and leaky vaults and cesspools of former days, quick-flowing drains have been substituted, in which the filth is still further diluted with all the water used in the city, and much of that which falls as rain. This last may either enter the sewers through the sluiceways in the streets, or it may soak in through cracks as ground-water, much in the same way that ground-water enters an agricultural drain.

With the introduction of the water-closet and the establishment of sewers proper for its use, all stagnant collections of putrescent matter in and about houses may be done away with. By means of the swift gush of water in the closet, the filth, while still fresh, is washed out of the house into the street sewer, while the gases of the sewer are (or should be) prevented from passing back into the house by means of a column of water, the so-called trap, held

permanently in the pipe which leads to the sewer. If the sewer have proper air-vents, so that there shall be no undue pressure upon the trap, the house is safe; that is to say, it is safe if the plumbers have done their work properly, and have not led a parcel of other pipes from bath-tubs and wash-basins into the water-closet trap.

It is manifest that sewers and water-closets must have very great merit as means for cleaning cities, if only there can be found outside the city some place where the contents of the sewers may be discharged without harm. Wherever the sea is within reach, or a great river, the sewage will naturally be discharged into it, with proper precautions, and so happily be got rid of. But with respect to inland cities the problem is far less simple, and many difficulties have been encountered in disposing of the sewage of such places ever since the use of water-closets became customary. Sewers cannot long be permitted to flow into small rivers, since the water is soon polluted, and made extremely offensive, and even dangerous to health. Hence many efforts have been made to purify sewage, either by means of filters or by chemical precipitants, by irrigation, or by soakage.

Purification of Sewage by Percolation.

Of the several plans above mentioned, the last named has approved itself to be commonly the best and the cheapest. It is evidently more generally applicable than either of the other methods. Mere "filters," i. e. filter-beds, whether of sand, gravel, or charcoal, such as are used for clarifying river-water, are of very little use in respect to sewage. They soon become clogged and impervious to the passage of the liquid, and even at the first they only stop the suspended mud, but not the matters which are actually dissolved in the water. To bring about the fixation or destruction of odors, coloring matters, and dissolved organic matters, to say nothing of ammonia and phosphates, the sewage needs to come into contact with great masses of earth, as when it is made to soak into a field.

As regards "germs," and microscopic organisms of whatever name, contained in the sewage, many of them will be strained out mechanically by the earth, as by any close filter; and some of them will be destroyed, no doubt, in the earth, by the ordinary microdemes which are contained in it, especially in the upper layers. It is not improbable that some of the most dangerous germs,

such as might infect or poison drinking-water by making it a vehicle for the transmission of specific diseases, may be killed in this way by the organisms naturally present in moist earth and in other decaying organic matters.

Intermittent Filtration.

It is a well-known fact that, when earth which has been soaked and saturated with sewage is exposed to the free action of air, many of the matters which have been absorbed by the earth are oxidized and destroyed. Undoubtedly this destruction depends largely, perhaps chiefly, on fermentations due to the presence of microscopic organisms in the earth, which require access to air in order to their best action. Hence the value of "intermittent filtration," i. e. of alternately soaking and aerating the soil. Practically, a number of acres of loose and open soil are underlaid with tile drains, at a depth of 6 or 8 or 10 or 12 feet, and the sewage is made to soak at intervals through one or another part of the field, or trenches are dug at intervals across the field, and filled with sand, upon the surface of which the sewage is made to flow. The idea is, that the whole of the foul liquid shall soak down into and through the soil, instead of flowing over it in good part, as happens in ordinary irrigation.

One instance has been reported, for example, where the sewage from a town of 40,000 inhabitants was disposed of on a field of 20 acres, which had been divided into four plots of equal size. The sewage was made to flow upon each of the plots for 6 hours at a time, and the land was then left at rest for 18 hours for aeration. Before coming to the land, the sewage passes through a strainer, to remove the coarser suspended matters, and is then either made to flow out upon the surface of the land, or through drain-tiles concealed beneath the surface. Sometimes ray-grass has been grown on the surface of such filtering fields, and this grass has been found capable of supporting enormous quantities of sewage in such situations.

In the instance here cited, the soil was a light loam upon a deep, gravelly subsoil. Under such conditions, it is said that the filtrate from the sewage flows out from the land to all appearance as clear and clean as ground-water usually is. Since only a comparatively small area of land is needed for putting this system in practice, it possesses an enormous advantage over methods in which the sewage is purified by methods of irrigation properly so called. It has

been claimed that some soils can clarify sewage in this way at the rate of 100,000 gallons to the acre per diem.

Purgation by Nitrification.

Since the nitrifying ferments play a very important part in the purification of sewage by intermittent filtration, it is evident that much more sewage can be adequately purified in a given time by coarse sand filters than by fine sand filters, though from the smaller quantity of liquid purified by the fine sand, minute solid particles, such as bacteria or the like, will be more completely strained out.

In Hazen's words, "The purification of sewage by intermittent filtration depends upon oxygen and time; all other conditions are secondary. Temperature has only a minor influence; the organisms necessary for purification are sure to establish themselves in a filter before it has been long in use. Imperfect purification for any considerable period can invariably be traced either to a lack of oxygen in the pores of the filter, or to the sewage passing so quickly through that there is not sufficient time for the oxidation processes to take place. Any treatment which keeps all particles of sewage distributed over the surface of sand particles, in contact with an excess of air for a sufficient time, is sure to give a well-oxidized effluent; and the power of any material to purify sewage depends almost entirely upon its ability to hold the sewage in contact with air. It must hold both sewage and air in sufficient quantities."

It was noticed that nitrification became less active whenever sediment from the sewage accumulated on the surface of the filter, and that in case the deposit was allowed to remain there long enough to exclude air from the pores of the filter, nitrification came to a standstill. It was found also that garden soil, peat and the like were so much inferior to sand that they are practically "entirely unadapted" to the purification, even of small quantities of sewage, in this way.

As a result of Hazen's experiments, it appears that filters of coarse sand, worked intermittently, are competent to clarify, well-nigh completely, 100,000 gallons of sewage per day and per acre, and that even when as much as 180,000 gallons per diem are filtered, something like 97 % of the organic matter may be removed. When worked at the rate of 60,000 gallons per day and acre, such filters can remove from 97 to 99 % of the organic matter of of the sewage, and yield a clear and colorless filtrate. On the average, the filters worked at this rate removed 99.9 % of the bacteria. Filters of fine sand can purify 30,000 gallons per day and per acre with almost absolute completeness.

Warington has suggested that in cases where particularly strong sewage has to be treated, an addition of gypsum might obviate

the necessity of great dilution, and permit of the liquor's being purified on a comparatively small area of land, since the gypsum would favor nitrification by destroying the undue alkalinity of the strong sewage. He remarks that in case a field is to be used for purposes of filtration, little would be gained by making deep filter-beds in the soil if it is at all heavy or apt to become consolidated.

That mere continuous percolation of sewage through earth may often be ineffective as a means of removing or destroying disease-germs, is evident enough from experience relating to the infection of well-waters by leaky cesspools. In such cases, the sewage has commonly flowed laterally through a non-aerated subsoil. It is to be remembered always that aerobic ferments need air, and that their best action will occur near the surface of the soil.

Denton has urged that even on sewage farms a sufficient area of land should be set apart expressly as a field for intermittent, downward filtration, which should serve as a sort of safety-valve for the irrigation operations, and be put to use at times when the crops might suffer injury in case the farmer were compelled to drench them unduly.

Muddy Sewage not good for Irrigating.

As has been said already, in respect to irrigation with river-water, it is not desirable that waters employed for continuous irrigation should hold much solid matter in suspension. There would be comparatively little harm, indeed, in causing muddy sewage to flow upon bare land which is to be ploughed subsequently, in preparation for grain or some other crop, provided the surface soil does not become coated with enough mud to hinder the downward percolation of water and the matters which water holds dissolved. But in case muddy sewage were used for irrigating a growing crop, the slimy coating deposited on the land would be apt to clog both the pores of the soil and the roots of the crop.

It is recognized by practical men in England that the suspended matter in raw sewage is a hindrance to successful irrigation, and that processes of clarification — whether by settling in tanks or by precipitating with chemicals — may greatly improve sewage for the irrigator, in spite of the fact that the clarifying process may remove from the sewage considerable quantities of fertilizing matter.

Purification of Sewage by Ferments.

The influence of micro-organisms in purifying sewage is so distinct and important that Alexander Müller has sought to systematize it and put it to practical use. He has devised a process, specially applicable no doubt to cases where no very large amounts of liquid have to be dealt with, which seems well adapted for purifying the drain-water from a country house, or that from certain factories, as those where beet-sugar is made. The idea is simply to foster, or even cultivate systematically in the sewage, organisms which shall feed upon the matters which might become offensive or dangerous if they were left to themselves. To this end, care must be taken to make the sewage neutral; to maintain it at a suitable temperature, i. e. to prevent it from cooling unduly; and to provide a complete supply of food for the desired organisms, by adding to the liquid, if need be, such ash-ingredients as may be required to supplement those already contained in it. The original intention was to "seed" the sewage by adding to it a quantity of the chosen ferment, much in the same way that yeast is used in bread-making: but practically it has been found that, during summer at least, this particular step is unnecessary, since an abundant supply of germs fall into the liquid from the air, and develop there freely if it is in a fit condition for their support.

This system of purification is evidently foreshadowed by the natural method which serves to clarify the water of rivers into which sewage has been poured. It is now recognized that the so-called self-purification of river-water must depend chiefly upon the action of "ferments" (the nitrifying ferments, among others), and upon algæ and other minute plants which live in the water and feed upon the organic matters which it contains.

Purifying Power of Earth.

It is of interest to note that the power of the surface soil to absorb and hold, and destroy foul odors, has really been put to use by men from the earliest times, and that the modern application of it to a matter so dilute as sewage is a mere modification of the method of burying which has so long been customary. Naturally enough, different kinds of soils vary considerably in respect to their power of purifying sewage. But it has been noticed in England, that even "slow soakage through a few feet of gravel destroys more organic matter than does a flow of many miles in the Thames." For that matter, it is now recognized that the

natural purification of river-water, after sewage has been mixed with it, is a much slower process than was formerly supposed, though it is true that various algæ, some of which are visible while others are microscopic, prosper in foul river-water and consume the organic matters which caused the pollution; and that the algæ in their turn support various forms of animal life. (Loew.)

From experiments made by the English Commissioners, it appeared, that, while a soil from Dursley that contained 18 % of oxide of iron and 43 % of silica purified sewage at the rate of 9.9 Imperial gallons per cubic yard per day, few soils could be found so good as this. A soil that will purify 8 gallons per cubic yard per day would be regarded as excellent. In case the field carried tile drains at a depth of 6 feet, there would be 9,680 cubic yards of filtering material to the acre; and at 8 gallons to the yard, the acre would purify 77,440 gallons. The Commissioners held that in laying out a filtering field there should be allowed one cubic yard of soil for 5.5 gallons of sewage. They found that under these conditions the organic carbon in 100,000 parts of sewage was reduced from 4.386 parts to 0.734 part, and the organic nitrogen from 2.484 to 0.108, and that the whole of the suspended matter was removed. Nitrates and nitrites were found in the effluent water, though not detected in the sewage previous to filtration. Of other soils experimented upon, one from Beddington purified sewage at the rate of 7.6 gallons per cubic yard per day, and exhibited a remarkable power of nitrification. But on doubling the amount of sewage, nitrification ceased, and the soil became clogged. A soil from Hambrook purified no more than 4.4 gallons per day, one from Barking 3.8 gallons, and peat 4 gallons.

In so far as nitrification is concerned, Alexander Müller has noticed that, when temperature and other conditions are favorable, the ammonia in diluted urine changes rapidly to nitrates, but that a diluted mixture of urine and solid excrement is much less subject to nitrification, perhaps because some of the offensive products of the putrefaction of fæces may be inimical to the life of the ferment. This observation goes far to explain a fact which has often been noticed; viz., that the waters of brooks into which mere urine has been poured clarify themselves much more quickly than do those which have received a quantity of night-soil.

Purification by Irrigation.

As has been said already in the chapter on Irrigation, it occa-

sionally happens that sewage may be usefully applied for purposes of irrigation, even in northern and humid countries, where waste land lies near at hand, and there are no neighbors to inconvenience. The process has undoubted merit, when circumstances permit of its being applied with economy, as in the case of public institutions, such as asylums, almshouses and reformatories, where labor may be furnished by the inmates without expense. (Rafter & Baker.*) In arid regions, where irrigation with mere water is habitually practised, sewage will naturally be put to use in this way.

What has just been said of the purification of sewage by filtration through earth will indicate, in some measure, both the merits and the limitations of the system of irrigation; for in one sense the latter is little more than a vague and incomplete process of filtration, though it is true, no doubt, that, in addition to the action of the soil and the air, the grass or other crop on the irrigated land, and the microdemes which live there, exert a powerful purifying influence.

Even when nothing more is done to foul sewage than to make it flow over a mere grass field, as at Edinburgh, many of its impurities will soak into the earth, or be absorbed by the plant-roots, or be destroyed by the micro-organisms in and upon the soil, and the liquid will be purified in a corresponding degree. But when, as happens in the best modern practice, the land is specially prepared beforehand for the irrigation, by laying down frequent tile drains throughout its length and breadth, it becomes a filtering field of considerable efficiency, through which large quantities of water must necessarily flow. Sometimes the ground is laid out in wide land-beds or "ridges," on which the crops are to stand, with channels at the tops of the beds through which to bring on the sewage, which runs thence down the sloping sides of the beds into another channel or furrow at the foot of the slope.

Another plan copied from an old French system of irrigating with mere water is to be seen near Paris, where some of the market gardens fertilized by means of sewage are laid out in narrow beds (2.5 feet in width), on which the crops are grown, with channels upon either hand as wide as the beds. These channels are flooded with sewage after the removal of each crop, and whenever the land gets dry. The growing plants have no direct communi-

* In their book entitled "Sewage Disposal in the U. S.," p. 225.

cation with the sewage, and no contact whatever with it, not even through the leaves; but food and moisture soak into the beds both from the right hand and from the left. The order of the beds is frequently changed, new beds being thrown up where the channels were and channels dug through the old beds. In this way half the land always lies fallow, as it were, and can be tilled for the purpose of destroying weeds, while it is fertilized both by direct absorption of sewage and by nitrification of the sewage. This system of "ridge and furrow" is specially applicable to crops of vegetables, i. e. to horticultural practice. By taking a little trouble, sewage can, of course, be applied to land where the slopes are steep or irregular, by the judicious application of engineering methods familiar to every professional irrigator.

Percolation cheaper than Irrigation.

Considered as devices for purifying sewage, filtering fields are superior to irrigated fields, merely because an acre of land arranged for intermittent filtration is competent to clarify a much larger quantity of sewage than can be clarified by an acre of irrigated land. The first thing to be considered, always, is the complete purification of the sewage, at (second) the lowest possible cost. But the system of irrigation always requires much land, in order that purification may be complete; and the presence of crops upon the land other than ray-grass is in some measure antagonistic to the free application of the sewage. That is to say, unless an extravagantly large area of land was available, strict justice would require the sewage to be put upon the fields at times when it could do no good to the crops, and even when it would be certain to harm them. Herein lies an evident danger, since the grower of the crops might sometimes wish to favor them at the risk of slighting his first duty of thoroughly purifying the sewage.

In order to diminish or to do away with some of the difficulties caused by too much water, it has often been proposed to establish two sets of sewers in cities — one for sewage proper, which may then be sent to the farm land, and one for the rainfall, which may be led directly to the river.

Both in establishing farms of irrigation and fields for filtration, it is essential that the engineers should take care that neighboring fields and farms are not drowned out by the ground-water which soaks out from the irrigated land, or which may be backed up behind it, as it were, through disturbance of the original course of percolation of the waters natural to the soil and the locality.

Amount of Land required to clarify Sewage.

It has frequently been argued in England, that, in order to dispose of sewage by way of irrigation, there will be required one acre of land, i. e. a square 70 yards to the side, for every 100 persons, and that the acre would purify 2,000 gallons of sewage per diem. Others have held that one acre will be needed for 150 persons, though there was at one time a successful sewage farm in England where an acre of land received the sewage of 60 persons.

The argument in favor of the number 100 appears to depend upon the dicta of men of experience, that an annual application of 5,000 tons of sewage to the acre gives the best practical results. In any event, this matter must be largely influenced by the climate, the character of the soil, and the amount of the rainfall, in any given locality. At Berlin, in 1890, each acre of the irrigated land received the sewage produced by nearly 200 inhabitants; and it has been said that on the sand-dunes of Dantzic, one acre is deemed to be sufficient for purifying the sewage of 600 persons, though in this particular instance complete purification can hardly be necessary.

At Paris, attempts to apply sewage in large quantities failed. It was found, indeed, on using the liquid at the rate of 40,000 tons per year and per acre, that the height of the ground-water was raised to such an extent that the neighboring land became water-soaked.

In the belief that the hot, dry, porous, sandy plain to which the Parisian sewage is applied could absorb, during the summer months, a much larger quantity of the liquid than any part of moist England, it had been calculated at first that each acre of the land could easily and profitably dispose of some 82,000 gallons of sewage applied to three crops a year at the rate of 27,000 gallons to each crop. But on this basis each acre would have received the sewage from 360 persons, while it has been thought by some observers in England that the sewage from 200 persons is the maximum amount that can be thoroughly absorbed by an acre of land under active cultivation.

More land will naturally be required to purify crude sewage than would be needed in case the sewage is first subjected to a process of treatment for removing the suspended matters, for the liquor thus clarified will be much less apt than the original sewage

to clog the soil and silt up its pores. At an irrigation farm at Barking, there were applied during one year 622,324 tons of sewage to almost 163 acres, i. e. about 3,800 tons to the acre. During another year the average quantity was 3,342 tons to the acre. On the most porous part of the farm as much as 960 tons have been applied in twelve hours.

On the basis that an acre of land is needed for each 100 of population, Wallace calculated, in 1881, that fully 10 square miles of land would be required in order to dispose of the sewage of Glasgow and its immediate suburbs by way of irrigation; or some 12 square miles, if the neighboring burghs were included.

Precipitation with Chemicals.

Many attempts have been made to purify sewage by adding to it chemical substances which should precipitate one or another of its constituents, and it was thought at one time that some matters of agricultural value might perhaps be saved from the sewage in this way. But nowadays the most that is hoped for is that the foul liquid may be sufficiently clarified by the chemicals to permit of its being allowed to flow into brooks, or small rivers, with a minimum of filtration through earth.

As has been shown under the head of Night-soil, no system of evaporating sewage to save the whole of the fertilizing matters, or of distilling it to save ammonia, can be thought of, because of their cost. But there are several methods, depending on the use of precipitants, which have been found to possess practical merit when employed under fit conditions, although none of them have fulfilled completely the expectations of their inventors. It has been found possible, for example, to clarify, by means of precipitants, small quantities of sewage, such as might come from a prison, or a hospital, and it is practicable also to purify in this way waste liquors from various kinds of manufacturing establishments. But none of the chemical methods have proved competent to deal with great masses of sewage such as are poured out from a large city, except, indeed, that precipitation may often serve as an ameliorant, or useful forerunner, to take out a good part of the impurities of the sewage, and so prepare it for subsequent thorough purification by processes of filtration through earth, or of irrigation.

One difficulty is, that all processes of precipitation are rather costly to begin with, since a considerable outlay has to be made on

account of the establishment in which the sewage is manipulated; the work needs to be done carefully and with intelligence, and at the best it is no easy matter to avoid stenches which are highly offensive to the neighborhood. There is a constant outlay, moreover, for chemicals, and no proper outgo can be found for the products of the precipitations, which collect as black muds, or sludges, of very slight agricultural value.

Generally speaking, sewage thus clarified by chemicals still needs to be filtered through earth before it can be turned into streams the water of which is employed for domestic purposes; though, as compared with the original sewage, the clarified liquor needs but little filtration, and in many places it can be discharged without any filtration at all. One point of some importance from the sanitary point of view is, that processes of precipitation may remove vast numbers of micro-organisms which — like other particles of suspended matter — become entangled in the flocculent precipitates, and settle out from the liquid with them. But it is still true that not all of the bacteria are thus removed from the sewage, not even when the chemicals employed are competent to act as germicides.

Another consideration is, that in many cases chemical precipitation removes from sewage a great quantity of papier-mâché which would be apt to clog filtering beds, since it would remain upon the surface of the soil as a slimy, impermeable coating. It is noticeable, withal, that sewage clarified by precipitation could readily be used for irrigation in localities where the application of crude sewage for this purpose might be objectionable or inadmissible. Several of the methods depending on precipitation are both interesting and instructive from the chemical point of view, as may be seen from the following statements concerning them.

The Lime Process.

On mixing a small quantity of milk of lime with sewage, as it flows out from a city, a light, flocculent precipitate forms; and on allowing the mixture to stand for several hours in a settling tank, the precipitate will subside, and carry down with it all the insoluble matters which were suspended in the sewage, together with about one-quarter of the matters that were held in solution in the sewage. Not only is some phosphoric acid thus thrown down, but soluble nitrogenized organic matters also.

The action of the lime depends in part, no doubt, on its power of coagulating or flocculating the matters suspended in the sewage, in the manner explained under the heads of Lime and Tillage. But it is true, also, that the lime combines with dissolved organic matters to form insoluble compounds, which envelop and entangle the finely divided suspended particles, as they cohere, and subside with them to form a soft, black mud of rather unpleasant odor. Meanwhile, more or less ammonia gas is set free by the action of the lime on ammonium salts in the sewage, and this ammonia acts as a vehicle to carry noxious odors into the air.

With regard to the union of lime with the soluble organic compounds, it would appear that the reaction is similar to that which occurs in the clarification of the juices of the sugar-cane and beetroot, when lime is made to combine with the analogous substances contained in those juices. However this may be, it is certain that the insoluble compounds produced when lime is added to sewage form a sort of network, which, in slowly sinking to the bottom of the tank, envelops and carries down with it most of the particles of solid matter contained in the sewage, so that the liquor is left tolerably clear, and fit to be run off into a river that is large enough to admit of the liquid's being speedily mixed with a great excess of water.

In spite of its appearance, the clear liquid is in reality far from being pure. It still contains some sulphuretted hydrogen, and so large a proportion of dissolved organic matters that it speedily ferments when left to itself, and becomes highly offensive. It needs to be diluted at once with a great volume of flowing water, or to be purified by filtration through earth, or by irrigation. It has not been found practicable to help matters much by adding chemical disinfectants to this liquid, though experience has taught that a somewhat better clarification of the original sewage may be obtained by supplementing the lime with a little sulphate of iron (or sulphate of alumina).

Not easy to get rid of the Precipitate.

Many difficulties have been encountered in England in trying to dispose of the sludge, i. e., the muddy precipitate which results from the addition of lime to sewage. It contains a considerable quantity of sulphide of calcium, which decomposes readily during the process of drying, with evolution of sulphuretted hydrogen. When spread upon the surface of the land, the peculiar character

of the mud so hindered it from drying in that moist climate that several months were required in order that it should become dry enough to be moved. Meanwhile, very unpleasant odors arose from the field in case the collection of mud was at all large.

It is to be presumed, withal, that not every soil would be improved by the application of so mud-like a material. It might serve well enough upon sands and gravels, and be actually hurtful perhaps on some good loams. At Leicester, according to Wallace, where a population of 120,000 yielded 7,000,000 gallons of sewage per diem, from 20 to 30 cwt. of lime were used for every million gallons of the sewage. The sludge, containing about 30 % of water, amounted to some 12,000 tons per annum. One plan for disposing of the sludge, that was tried long ago, was to convert the wet mud into a coherent paste by whirling it in a centrifugal machine, to mould the paste into bricks, and to dry them in the air. Such "Leicester bricks" contained, when air-dried, from 1.5 to 2 or 3 % of phosphate of lime, from 0.5 to 1 % of nitrogen, and perhaps 0.25 % of potash. Considered as a manure, they were manifestly not worth the cost of much transportation, for it will be noticed that the nitrogen in such sludge cannot have been of very high grade. Practically, it was from the first a very difficult matter to induce farmers to use these bricks, even in places where no overwhelming quantities of the mud were produced, while for large cities the disposal of the sludge was a mere bill of expense.

Another method of procedure is to run the sludge through a filter-press, and thus obtain solid cakes which can readily be handled and transported. But, excepting some special localities where the soil is of such character that the sludge may serve as an amendment, as well as a manure, it has not been found practicable to sell this waste product, or even to give away any large amount of it. Analyses of air-dried sludge from Birmingham, by Wallace, showed half of one per cent of nitrogen, from 1 to 1.5 % of phosphate of lime, about 12 % of lime, 13 % of water, and 20 % of organic matter.

Cement made from Sludge.

One ingenious scheme, invented in England by General Scott, was to add clay as well as lime to the sewage, in order to precipitate the impurities, and subsequently to convert the clayey sludge into cement by burning it. It was argued, in view of the large

amount of organic matter in the sludge, that comparatively little coal would be required for the final act of burning, though of course the moisture in the muddy precipitate has got to be dried out somehow. Cement of very tolerable quality has actually been prepared in this way, and it was thought that the making of it might possibly be a cheap method of getting rid of the sludge in some localities, though no actual money profit could be gained. After trial, the process has been abandoned.

Possibly the sludge might be burnt in furnaces specially adapted for the combustion of wet fuel. Such furnaces have long been in use for burning bagasse, wet peat, spent tan-bark, and spent dye-woods; though perhaps in the case of the sludge some refuse coke or coal might have to be mixed with it to insure its ready combustion. Moor has suggested that pressed sludge-cake might be distilled and burned in a kiln or furnace arranged on the well known principle that a layer of the material shall be kept in active combustion at the bottom of the furnace, and thus afford heat for drying and distilling the material above it. On this plan, moisture, ammonia, tar and inflammable gas would be continually distilling off from the layers immediately above the fire, and ashes would be continually dropping away from the fire, so that dried and carbonized sludge would constantly settle down into the fire, there to be burned. A certain economic advantage might be gained from the ammonia, etc., which would be collected and sold, and the ashes would be fit to be thrown away anywhere without offence. The chief objection to any plan of combustion or distillation is that special pains would have to be taken to burn and destroy the highly offensive gases which would be evolved.

Yet another device, more recent than the plan of making cement, is to precipitate the sewage by means of lime and copperas, to press the sludge into blocks as if it were clay, to carry these blocks to sea, and discharge them there into deep water, out of the way of doing any harm.

As with the other processes of precipitation, the disposal of the lime sludge is really the most serious practical difficulty that has been encountered in working, and the remark is specially true of large cities, where the quantity of sludge produced is enormous. English farmers will not buy it when dry, at a price equal to the cost of drying, nor will they take it as a gift when wet, except in insignificant quantities. In many localities it has been used for

filling up waste places. Wallace computed, in 1881, that the sewage of Glasgow, then amounting to from 40 to 70 million gallons daily, would produce every day 135 tons of dried sludge. In the moist state this sludge would amount to five times these figures, or 675 tons, an enormous quantity of material to be disposed of daily. If lime alone were used as the precipitant, 40 tons of it would have to be used daily. He urges that no town or city should adopt a system of precipitation until it is clearly seen how the sludge is to be disposed of.

One objection to running sewage clarified by liming directly into brooks is that the free lime contained in it is hurtful to fish. Filtration through earth does away with this trouble, or even filtration through coke slack, whereby the lime is retained or neutralized through absorption of carbonic acid from the air. According to Landgraf, it would be possible to remove the excess of lime, and some organic matter also, from the liquid portion of sewage that has been clarified by liming, by agitating the liquid with air, or throwing it as spray into the air, or by making it flow through racks filled with fagots, as in the process of "graduating" brine, mentioned in the chapter on Night-soil.

Precipitation with Magnesia.

The old idea that ammonia and phosphoric acid might be economically saved from urine, by precipitating them with magnesia, was disproved long ago, as has been set forth under the head of Night-soil; but the use of magnesia in conjunction with lime, as suggested by Suvern, has found frequent application in Germany for purifying small quantities of sewage and factory wastes. Suvern made a mixture of 70 parts of crystallized chloride of magnesium, 100 parts of quicklime, and 7 or 8 (one account says 18) parts of coal-tar, heated together; and he finally added enough water to make a thin paste containing some 9 or 10 % of solid matter. By virtue of chemical reactions in the mixture there were formed hydrate of magnesia and chloride of calcium. But beside these substances there was the tar and an excess of hydrate of lime, and it will be noticed that the presence of this lime brings the process into relations with the "liming" process above described.

Suvern's thin paste was made to flow continuously in a fine stream into the current of sewage, so that it should mix therewith. The moment it came in contact with the sewage a voluminous light

precipitate of phosphate of ammonia and magnesia, as well as of lime and organic matter, was formed, which carried down with it all the suspended matters of the sewage.

The mixture of liquid and precipitate was made to flow into appropriate tanks, where the precipitate settled out quickly, and so completely that the water flowed off clear and pure enough to be turned into rivers, though not into brooks. The liquid still contains much organic matter, and undergoes fermentation in the course of a few days. As much as 1.5 parts of solid matter have been found in 1,000 parts of it. It has been stated that about one-third of the nitrogen in fresh sewage can be precipitated in this way, and nearly the whole of the phosphoric acid. As for the rest of the nitrogen, one-third of the original quantity escaped in the form of ammonia gas, and the other third remained dissolved in the water, in the form of urea in this particular case.

Samples of dried mud from Suvern's process have been found to contain 1.5 % of phosphoric acid, 0.75 % of nitrogen, and 20 % of organic matter (including tar). But in field-practice the mud has been found to be practically worthless as a manure, possibly because of the tar which adheres to it. Experiments made upon farms near Berlin showed that the Suvern precipitate was not worth the cost of transportation, even at a distance of only a few miles.

Alumina as a Precipitant.

Travellers have long been accustomed to use alum for clarifying the water of bogs and foul pools to fit it for culinary purposes. It is a substance even more effective than milk of lime for causing the flocculation and precipitation of the colloid clay of mud-puddles, and in case soluble organic matters are contained in the foul water the alumina in the alum, or rather a basic sulphate of alumina, combines with the organic matter to form a bulky gelatinous precipitate, which drags down with it impurities that were suspended in the water. So, too, alum, or better, a cheap sulphate of alumina containing some ferrous sulphate, has often been used to clarify sewage. It was thought formerly that the action of aluminum sulphate might be made specially effective by adding, at the same time with it, enough lime to neutralize its acid, and so set free the whole of the alumina, though when the sewage contains enough free ammonia to decompose the sulphate of alumina no lime is needed for this purpose.

Practically, Hazen has found that lime is not necessary. Although the precipitation is a little more rapid when lime is used, the small gain in time hardly compensates for the extra expense. Actually it is found that a very small proportion of the aluminum sulphate is competent to precipitate the visible impurities out of a comparatively large quantity of sewage, quickly and wellnigh completely, and at the same time to deodorize the sewage. Since the whole of the phosphoric acid in the sewage, and a little of the ammonia, as well as a considerable part of the organic matter, are carried down with the alumina, hopes were entertained at one time that the precipitate might have some value as a fertilizer, and experiments made at Paris with very large dressings of it seemed to support this view. But the analyses of Voelcker show that it must be wellnigh worthless, and the same conclusion was reached by means of field experiments upon farms near Berlin. Like street-sweepings, earth-closet refuse, and many other things, the precipitate would be worth strewing upon farm-land if it could be brought there without expense. But it is so nearly valueless that it cannot bear the cost of transportation.

It is said that the alumina precipitate settles rather more quickly than that produced by lime; that less sludge is formed by the alumina; that the process requires less labor than has to be expended in working the lime process, and that the thorough removal of the phosphoric acid makes the liquid clarified by alumina somewhat less liable to putrefy and to stand in need of less filtration through earth than that clarified by lime. It is said to be practicable by the use of alumina (or of ferric salts) to remove from one-half to two-thirds of the organic matter in sewage. On the other hand aluminum salts, though more convenient of application than lime is, cost more than lime. At Paris it was found that the mere cost of the materials used was equal to the fertilizing value of the sludge. Analyses made at Paris showed: Nitrogen in original sewage, 0.037 kilos; in clarified sewage, 0.021; volatile and combustible matters, 0.729 and 0.240; mineral matters, 2.038 and 0.724. Or, total matters in sewage, 2.804, and in the clarified liquor, 0.985. The clarified water still contained two-thirds of the nitrogen of the sewage, and one-third of the organic matter.

At Dortmund, in Germany, the sewage is allowed to deposit its heavier impurities in special basins before being subjected to

chemical treatment. The still turbid liquid is then mixed in a tank with milk of lime and a solution of sulphate of alumina, and run off into deep pits to settle. Analyses of the mud from the first basins, and of the sludge from the settling pits have been made by Koenig, whose results are given in the following table: —

Percent of	In the Mud.	In the Sludge.
Water	50.00	40.00
Organic Matter	18.63	17.71
Ash	31.37	42.29
Phosphoric Acid	0.37	0.55
Potash	0.12	0.11
Lime	2.69	14.95
Magnesia	0.19	2.20
Nitrogen	0.74	0.43

In England, Spence & Sons have put on sale an "alumino-ferric cake," consisting of the sulphates of alumina and iron, as a substance extremely well suited for the treatment of domestic sewage, by way of precipitation.

Alumina after Lime.

Another idea of Mr. Spence was to use sulphate of alumina after lime, i. e. to add the alumina salt to sewage which has already been clarified by liming it. Hereby a new quantity of organic matters are thrown down, while the free lime in the liquid is neutralized. Sewage thus doubly clarified might perhaps be thrown into small rivers without need of any earth filtration. Spence suggests that by adding dilute sulphuric acid to the alumina-sludge obtained in this case, the sulphate of alumina might be revivified, and so be used over and over again, while organic matters would be obtained incidentally that would be fit to be sold as a fertilizer.

Phosphate of Alumina and Magnesia.

A process proposed by Forbes and Price in England is somewhat akin to that of Suvern. The idea was to add to the sewage a mixture of a magnesium salt and phosphate of alumina dissolved in sulphuric or muriatic acid, together with enough milk of lime to neutralize the acid by which the phosphate was held dissolved. The organic matter of the sewage goes down with the phosphate of alumina, and the ammonia with the phosphate of magnesia, and the suspended matters are enveloped in the precipitate as before.

The operation is said to be very simple, no apparatus being required, except a reservoir or tank to hold the sewage while the

chemicals are added to it. The precipitation, moreover, is so complete, that the water which flows away is transparent and colorless, and to all appearance pure. Native phosphate of alumina, such as is found in considerable quantities in the West Indies, was employed, and the sludge was to be used as a phosphatic fertilizer.

Since hydrated phosphate of alumina, as thus precipitated, is much more readily soluble in carbonic acid and other solvents than the native phosphate is, it was argued that each pound of phosphoric acid in the sludge would be worth at least twice as much for fertilizing purposes as when it was in the original mineral, and that the cost of clarifying the sewage might be nearly or quite offset by the gain in value of the phosphate used. A sample of this phosphatic sludge prepared and analyzed by Voelcker contained nearly 29 % of precipitated phosphoric acid.

Phosphate of Lime.

The process of Whittbread consists in adding superphosphate of lime to the sewage until it exhibits an acid reaction, and then enough milk of lime to neutralize the mixture. Di- and tri-phosphate of lime are precipitated together with organic matters entangled and combined both with the lime and the phosphates. Nine-tenths of the suspended organic matter of the sewage is removed together with a third of that which was held in solution. Practically, all the phosphoric acid of the sewage is precipitated, but none of the ammonia. The sludge is in this case always highly phosphatic, of course, though it sometimes contains very little nitrogen. Petermann found no more than 0.6 % of nitrogen in a thoroughly dried sample of the sludge, and nearly 10 % of phosphoric acid, half of which was soluble in citrate of ammonia. In another sample Russell found 2.5 % of nitrogen. The clear liquor which separates from the precipitated sludge still contains much fermentable organic matter, and must, usually, be subjected to further purification, either by way of irrigation, or by intermittent filtration through earth.

The A B C Process.

This process depended upon the use of alumina (in the form of the impure sulphate, or of alum), blood, and clay and charcoal. It is known in respect to clay that when, by the addition of alum, or albumen, or gelatine, it is flocculated in the midst of a foul or muddy liquid, it will carry down with it when it settles a mass of suspended matters, and leave the liquid clear. The purpose of

the blood, as in sugar refining, is that, by the coagulation of its albumen, special coherence may be given to the precipitated matters. As with the other processes of precipitation, so with this one, the suspended matters of the sewage were well removed; but so much of the organic matter remained in solution, that the clarified liquid soon putrefied on standing. The sewage was no better cleansed, in fact, than it was by the process of liming. Unpleasant odors arose during the drying of the sludge, though when dry it was free from smell. It has a somewhat higher agricultural value than the lime sludge, though it was found impracticable to sell, or even to give away, any large quantities of it.

The idea of using clay in this way was not wholly devoid of merit, for it has been noticed in purifying drinking waters that those naturally charged with clay may be readily clarified by adding chemicals proper to coagulate the clay, while other waters, free from clay, which are highly charged with certain forms of organic matter, cannot be properly clarified by mere coagulants, though on adding clay together with a coagulant the organic matters will speedily settle out.

In five samples of dry A B C sludge, Voelcker found, among other things, 6 to 8 % of water, 10 to 22 % of organic matter, 38 to 60 % of clay and sand, 1 to 2 % of nitrogen, and from 2.5 to 4.3 % of terphosphate of lime. An analysis by Way showed 36.2 % water, 2.63 % phosphate of lime, 0.62 % nitrogen, and 20.35 % carbonate of lime. Another, by Petermann, showed 11.37 % water, 1.4 % phosphoric acid, 0.82 % nitrogen, 1.66 % potash, and 3.57 % lime in the dried precipitate.

The Chloride of Iron Process

has been found to be highly efficient for clarifying sewage, though it is too costly to be used on a large scale. Impure ferric chloride is used, much in the same way that sulphate of alumina is, as explained above. A heavy precipitate of ferric hydrate is formed, which carries down mechanically the suspended matters. Sulphuretted hydrogen is arrested also as ferrous sulphide, and phosphoric acid goes down as ferric phosphate. Since it is so highly charged with iron oxide, the sludge can hardly have much value as manure. In some cases a solution of the iron chloride and milk of lime are made to flow simultaneously into sewage or into drain-water from beet-sugar factories.

Sewage clarified by the iron process, or by the use of other me-

tallic salts, such as chloride of zinc or chloride of manganese, may ferment in warm weather in the course of a week or ten days; but it does not putrefy so readily as that clarified by the processes previously described. During an epidemic of cholera, in 1884, Doesburg, at Rotterdam, set up an establishment for purifying the water of the river Maas, on the large scale, by means of ferric chloride, in order to make it more fit for domestic use. The sludge obtained in this case contained 33 % of organic matter and 1¼ % of nitrogen. Heaps of it soon passed into a condition of violent and offensive putrefaction.

Another way is to use cheap ferric sulphate prepared by drenching roasted pyrites with enough strong sulphuric acid to form a thick paste, which is kept for several hours at a temperature of 100° to 150°, with occasional stirring. There is obtained a dry pulverulent mass the surface of which is covered with a whitish layer of ferric sulphate. Solutions of the sulphate of any desired strength are obtained by mixing the mass with definite quantities of water. These turbid solutions are said to purify sewage more completely than milk of lime does. The precipitate settles very quickly, and the effluent water is clear, colorless, odorless and neutral or slightly acid, while that from the lime process is alkaline and colored, and retains suggestions of an offensive odor. From the very fact of its alkalinity, the limed liquor soon undergoes putrid fermentations. Hazen, who has obtained highly satisfactory results by using ferric sulphate, finds that this substance can perfectly well be used by itself. On adding lime, it appeared that the latter had very little influence to increase the efficiency of the iron salt. He obtained better results on the whole with ferric sulphate than with sulphate of alumina.

Copperas (Ferrous Sulphate)

has sometimes been used in conjunction with lime for clarifying sewage, although it is less convenient of application than the ferric salts and is somewhat inferior to them, because ferrous hydrate is less completely insoluble than ferric hydrate is. By itself, copperas is practically useless, but when added in sufficient quantity to sewage which has already been mixed with lime, it can do good service. (Hazen.)

CHAPTER XXXIV.

THE DISPOSING OF FARMS.

It is of the nature of a self-evident proposition, that the modes of arranging and managing different farms, even under one and the same climate, must differ widely, according to varying local circumstances. One set of conditions will lead to sheep-farming, another to cattle-grazing, another to dairy-farming, another to the production of grain, or hay, or cotton, or tobacco, or sugar, or some other special crop, while other conditions still will lead to the establishment of farms of mixed cultivation.

Since many of the conditions that go to determine the character of a farm may fairly enough be classed as chemical, it is always interesting to consider any given farm from the chemical point of view, and to try to pick out the facts concerning it which specially belong to this category.

Naturally enough, it is no easy matter to do this. The subject is complex and intricate at the best, and it is commonly difficult to separate the chemical items from a multitude of others, — social, political, and mechanical, — which are of equal or even of greater importance than the chemical considerations, but which tend to interfere with and obscure them. It is true, however, that glimpses can be got which are often highly instructive.

The significance of peat, of clay-burning, of fallows, of manure from cattle and sheep, and from cities, of rockweed and kelp upon a seaside farm, of water upon irrigated land, and in soils of good capillary character, is plain to common observation. Many analogous illustrations will readily suggest themselves. Hence an incentive to discuss in a general way some of the circumstances upon which different classes of farms depend, and to point out the dispositions of some individual farms which illustrate or enforce chemical principles.

Enduring Fertility of Bottom-Lands.

Upon the highly nitrogenized, fertile, moist soil of certain river valleys at the West, where Indian corn has been grown year after year for a century without interruption and without manure, it is certain that the farmer will have no very strong incentive to vary his crop or his modes of cultivation, provided a market for the grain is readily accessible. But if land like this is far from a market

for grain, indirect methods of converting the grain to money will be resorted to. The system of farming will be changed in so far that the corn shall be fed to swine, and so converted into pork, or it will be fermented and distilled into the form of whiskey. By these devices the original crop is simply concentrated, as it were, and made compact, so that it can be carried with profit to a distant market. Other examples of devices for condensing crops so that the natural products of the land may be made compact enough to bear the cost of transportation are seen in the conversion of grass into wool, and of grass and corn into butter, cheese, and fat cattle.

Beside distance from a market, there are other considerations which might make the systems based upon whiskey-distilling or pork-feeding preferable to that of mere grain-growing. Suppose, for example, that the fertility of the land, though very great, is not inexhaustible, why then either the making of whiskey or of pork would enable the farmer to obtain manure wherewith to keep up the quality of his land, or even to enhance the value of it. One common way at the Western farms of checking the tendency to exhaustion is to harvest only the finest ears of corn, and to turn a drove of hogs into the corn-field to utilize what is left. When whiskey is to be made, the starch of the corn is converted by fermentation to sugar, and the sugar in its turn to alcohol, which, in a somewhat diluted form, is distilled off from the mixture of water and the non-amylaceous constituents (nitrogenous matters, cellulose, ash-ingredients, etc.) of the grain. Upon this residual "slop" neat cattle are fattened.

Land so excessively fertile as that of some of the river-bottoms in the Western country is not peculiar to America. The Nile valley offers a striking instance of the same kind of land. The fertility of the soil upon the banks of that river is so great that manures were but little employed there formerly. Travellers have often referred in terms of astonishment to the enormous heaps of refuse which accumulate in the vicinity of the Egyptian towns; and, as is well known, the saltpetre earths of Egypt are from similar mounds of refuse left by former generations of men. It is to be said, however, that since the cultivation of the sugar-cane (and of cotton) has become important in Egypt, it has been found to be advantageous to apply artificial fertilizers freely to these crops, in order to keep the soil in good heart, for the deposition of river-

mud on the land would be inconvenient in these cases. By means of "summer canals" also, a continuous system of irrigation is practised, even on lands not immediately adjacent to the river, in order that these plants may grow freely during the hot months.

So too in Palestine. The fertility of the valleys, where irrigation is possible, is very great. Dr. Hooker has said that he would engage to supply the whole population of Syria with food from the produce of ten well-cultivated miles of the valley of the Jordan.

Embanked salt-marshes often exhibit enduring fertility, as in Holland. At the Bay of Mont St. Michel, in France, barley grown in alternation with wheat and rape on reclaimed marsh-land is said to yield at the rate of 36 bushels to the acre and to have straw as thick as a man's little finger. No manure is applied, and the straw is sold off the farm. Fine asparagus is grown there in large quantities almost without care. On less fertile marsh-land, at the other end of the bay, wheat produces 32 bushels and more to the acre in a rotation of wheat, clover and rape; the second growth of clover being ploughed under.

Farms in Sterile Hilly Districts.

In contrast with these fertile river-bottoms may be cited a country of steep and rocky hills. Here the only alternative is pasture or woodland. But there are a great variety of dispositions possible nevertheless. Some of the small New Hampshire rivers, like the Pemigewasset, which flows from the Franconia Notch into the Merrimack, and the Saco River in the Conway region, carry tolerably wide intervales in the heart of a very broken and hilly country. The prevailing disposition of farms in that region is a quantity of hill-land behind the homestead, and a strip of intervale in front. Sheep are pastured on the wild hills through the summer, and kept up in winter upon hay grown upon the intervale. A little maize and a few potatoes and oats are grown, of course, and a few cattle are kept, as well as the sheep; but the basis of the farms is sheep, in many instances. It is so hard a matter to carry on profitable husbandry in that region, excepting where the fertilizing influence of the river is felt upon the bottom-land that the hill farms, properly so called, i. e. those situated wholly upon the hillsides, and devoid of intervale, are falling away every year. Their owners desert them, house and land together, and move away to some happier clime. No doubt this emigration might be checked by the introduction of rational systems of recuperating the worn-

out pastures of the hill farms, and by the judicious use of composts (made from peat or sods) and of artificial fertilizers on those patches of land which are smooth enough to be mown. Rough and ready methods of drainage also, and of irrigation, might doubtless be used in some places; but it is hard to introduce innovations such as these, so long as there is richer land at the West to be had almost for the trouble of taking it.

Darwin, in his "Narrative of the Voyage of the Beagle," has described a somewhat similar state of affairs as existing in Chili. Between the parallel mountain ranges of that country there are numerous level basins, or plains, which are easily irrigated, since they slope naturally towards the sea, and there is no lack of water from the hills. Thanks to the irrigation, these plains are singularly fertile, though, without irrigation, the land would yield nothing, for during the whole summer the sky is cloudless. The mountains and hills are dotted over with bushes and low trees, and excepting these the vegetation is very scanty. Each land-owner in the valley possesses a certain portion of hill country, where his half-wild cattle in considerable numbers manage to find sufficient pasture. Once every year there is a grand "rodeo," when all the cattle are driven down, counted and marked, and a certain number separated to be fattened in the irrigated fields. Wheat is extensively cultivated, and a good deal of Indian corn. A kind of bean is, however, the staple article of food for the common laborers.

In the early history of England, before clover or turnips were cultivated, the wealth of the farmers consisted chiefly of cattle, sheep and swine; but in the lack of fodder enough to support many of these animals through the winter, it was customary to slaughter and salt down in the autumn all those which were in fairly good condition. Usually, only young animals and breeding animals were carried through the winter, for, in default of generous winter fodder, the animals which had become fat in the pastures would inevitably have grown lean long before the next spring. A somewhat similar system is still pursued on the bleak mountain pastures of Scotland and Wales, only that instead of the animals being killed at the farm they are transported to richer farms in England to clear up the pastures there and to be fully fattened afterwards upon turnips and oil-cake.

Farms maintained by Forage Crops.

Between the two extremes just mentioned, viz. the inexhaustible

river-bottoms of the West on the one hand, and the rocky pastures of New Hampshire on the other, may be found an almost infinite diversity of arrangements. A good example of the way in which the continual grain-growing of the West has to be modified as the quality of the land begins to depreciate, may be seen in New York and Ohio, where clover-crops are often made to alternate with wheat, as has been stated under the head of Rotations. The clover-fodder may be used of course to produce dung, or the plant may be grown merely for the sake of bringing nitrogen from the air to the soil. At the South, the cow-pea serves instead of clover, and in some instances it appears to be an excellent alternative. A rotation practised in some parts of Georgia consists of oats and cow-peas, as follows: Oats sown in October are ready to cut by the middle of May. The oat-stubble is ploughed under, cow-peas are sown, and the vines are mown for hay in August. This hay is said to be of excellent quality. The second growth of the peas is ploughed under, and oats sown again in October or November. This rotation may be kept up for long terms of years, — "forever," as the saying is in that locality.

A somewhat similar method is practised in Australia, where, in default of clover — which can only be made to grow by taking much trouble — crops of peas are grown occasionally for the purpose of refreshing land, the fertility of which has been impaired by continually growing wheat upon it. After the peas, wheat is found to do well, even upon land which has been a good deal exhausted by incessant wheat-growing. (Macivor.) An analogous example of the need of interpolating leguminous crops as a means of refreshment may be drawn from English experience. It is said that stiff soils are peculiarly adapted to the growth of wheat in that country. When drained, well-cultivated, and limed, they grow beans, also, better than any other sort of land. Hence there must have been a time not long ago when, theoretically speaking, by far the most profitable crops that could be grown on rich clay soils, in some parts of England, would have been wheat and horse-beans. The products would have been readily salable at high prices, and the two crops suit one another extremely well when grown in alternation. But in case this experiment had been tried upon an entire farm, it would probably have happened — in spite of the power of the bean-roots to get nitrogen by way of symbiosis — that not enough manure could have been obtained

from the bean-refuse and haulm and from the wheat-straw to keep up the fertility of the land. Nowadays such a farm could probably be maintained readily enough by means of artificial fertilizers, though it might no longer be profitable to do so in England because of free trade in grain.

In case it were proposed on any farm to pay special attention to the two crops now under discussion, the question would need to be considered whether or not it would be profitable to grow on that farm enough hay to support the work-horses and a cow or two, or perhaps even to grow oats for the horses, rather than to buy these products. In some situations, doubtless, there might be a certain incentive to practise mixed cultivation for the sake of obtaining some forage.

In point of fact, on some heavy clay lands in England, unsuitable for root-crops, the following rotation was practised: 1, Horse-beans (manured); 2, barley (or oats), with grass and clover; 3, grass and clover for one or two years, according to circumstances; 4, wheat. Another plan sometimes adopted on land of medium texture suitable for root-crops was to grow beans half as often and to take a crop of roots, instead of the beans, every second course, in the above-mentioned rotation.

A somewhat similar example has been noticed in Germany, in respect to wheat and rape-seed, i. e. two merchantable and, at one time, highly profitable seed-crops, which might be grown alternately on some soils if it were not for the need of growing forage, in order to obtain manure with which to feed them. As has been said, many German farmers took advantage of the introduction of guano to grow, by means of it, more frequent crops of rape-seed than they had been able to take previously.

It is to be borne in mind that, previous to the introduction of artificial fertilizers, and the establishment of the custom of feeding animals on oil-cake, bran, and other mill products, the farmer's chief hope was to get more manure by increasing his flocks and herds; but in order to maintain these animals he had first of all to grow crops wherewith to feed them.

Potato Farms.

Formerly much more than now, i. e. before the advent of the fungus which caused the disease known as the potato-rot, many farms in certain parts of New England were based on the growing of potatoes. On the coasts of New Hampshire and Maine, and of

Nova Scotia also — wherever, in short, there was access to water carriage — the potatoes were shipped as such, to be eaten as such, while in the interior of the country starch was made from them; that is to say, they were converted into a substance easily transportable, for which there is a constant and large demand all over the world. The refuse from the starch factories has a certain small value as cattle-food, and a part of the crop itself was not infrequently used as fodder, and so for the production of dung, and the potato-vines were left upon the land; but the main point was that a non-exhaustive merchantable crop was produced as the chief resource of the farm. Usually the potato-crops were supplemented with moderate crops of forage and grain, for household use and for the support of cattle which ranged in pastures during the summer.

It is difficult for anyone who was not actually upon the ground at the time to realize the terrible destruction of farms that was caused in Nova Scotia in particular by the potato disease of 1847–48. So, too, in Ireland, where, as is well known, the moist climate is particularly suitable for the growth of potatoes. Previous to the advent of the rot-fungus — which, in 1845 and 1846, caused a fearful famine in Ireland — potatoes flourished there better than in most other countries, and they were grown in enormous quantities. Stories are told of crops amounting to even a thousand bushels to the acre.

In Scotland also, very large quantities of potatoes were grown formerly, and the change from this crop to turnips, at the time of the rot epidemic, had no little influence in helping to introduce phosphatic manures into general use. On seeking to substitute turnips in the rotation of crops, instead of potatoes, when the latter could no longer be counted upon, it was found that farm-yard-manure, when used by itself, did not produce such large crops of turnips as could readily be grown when guano and bone-meal, or superphosphate were added to the dung.

It is said that the increase due to the use of the artificial fertilizers often amounted to 5 or 6 tons per Scotch acre, or to nearly one-half more than had previously been got by dung alone. It was argued at the time that the guano and the superphosphate enabled the young plants to get well started, and that the bone-meal sustained the crop through the later stages of growth. But, in the agriculture of the locality, a large crop of turnips means

many sheep to eat the turnips upon the land; and the increased number of sheep will manure and trample the land more completely. Moreover, by judiciously combining the purchased phosphates with the manure produced upon the farm, it became possible to fertilize large areas of land for the growth of turnips, and to abandon bare fallows altogether.

In point of fact, the change from potatoes to turnips, and the use of phosphatic manures as above described, was followed in some parts of Scotland by unusual agricultural prosperity during a long term of years. It was not alone that the turnips gave profit directly in the form of meat, but that the cultivation of them helped to clean the land, and that, when the roots were eaten off by sheep, the land was so thoroughly enriched and consolidated that excellent crops of grain could be grown upon it.

Influence of Maize on Farming Methods.

In Germany, starch, whiskey and sugar (glucose) are still made from potatoes, upon a very extensive scale, and many farms based on potatoes exist in that country. But here in America maize has largely replaced the potato as a source of these products. Indeed, Indian corn, which has always been the basis of American farming, has become more than ever conspicuous since it has pretty thoroughly superseded the potato as a starch-producing crop. Maize is remarkable, not only for its easy cultivation and for the fact that, when well manured, it can be grown after almost any other kind of plant, but for its enormous yield both of food and of fodder. It is at once a grain-crop and a forage-crop; or, even more emphatically, a bread crop and a fallow-crop.

It was at one time laid down as a precept of political economy in Europe, that in order to ensure the subsistence of a nation its agriculture should be based on at least two kinds or classes of crops, and that the second or inferior class — though specially suited for the maintenance of animals, and ordinarily put to use for this purpose — might in times of dearth be made to serve as human food, together with the meat of animals that had been reared by means of it. After the introduction of the potato, and before the advent of the fungus which causes the disease known as potato rot, it was thought that the requirements of the maxim had happily been fulfilled, and it is true enough that the potato has the merit of being an underground crop, which is not exposed to precisely the same kinds of risks of injury as the cereal grains are, and

that it will grow very well in several northern countries which are not hot and dry enough to ripen Indian corn.

But it is manifest in all places where maize can be grown and ripened with ease and certainty that it must be better fitted than the potato to serve as a supplement to the cereal grains. In any country where wheat (or rye) and maize and potatoes are all familiar crops, there can be little risk of dearth. Witness, for example, the rapid settlement of this country in the face of many obstacles, and the ability of the young United States to endure the strain of two wars with England, and more particularly the fact that the armies of the Southern Confederacy were easily fed during several years in spite of conscriptions, blockades and other military interferences.

Maize versus Roots.

The wellnigh universal cultivation of Indian corn in this country has, practically speaking, done away with the need of growing roots as cattle-food, and it has enormously curtailed the growing of leguminous forage crops also. Occasionally a few roots are grown among us, here and there, to be fed out as a relish to animals, but now that the method of preserving corn-fodder in silos has become generally understood, it seems improbable that roots can anywhere hold way with Indian corn in places proper for the growth of the latter.

It was, however, long a debatable question whether there might not be in some situations a possibility of arranging farms on some system of root-growing. As long ago as 1816, the famous English political writer, Cobbett, proposed to base a farm on Long Island, 20 miles from New York, on rutabagas, cabbages, and Indian corn, as follows: The idea was to have a farm of 100 acres, of which 12 acres should be in rutabagas, to yield 500 bushels to the acre; 15 acres in corn, well tilled, with white turnips sown at the time of last ploughing, to yield 40 bushels shelled corn and 1 ton of stover to the acre; 3 acres of early fodder cabbage, planted at various times [according to a French practice]; one acre of mangel-wurzel; one of carrots and parsnips; and 12 acres of orchard kept in grass. The rest of the farm would be devoted to hay and grain for sale.

He would keep 4 working oxen, 3 cows, and 14 breeding sows all the year round, and at least 100 ewes; would begin to feed rutabagas on the 1st of February, when they are at their best, and

would sell off fat stock during the spring. By the 1st of July he would put the ewes upon cabbage, and fat them therewith, in addition to the grass of the orchard. Cabbages, fall-feed from the grass- and grain-fields, and corn-stalks, were to carry the stock until the 1st of December, when white turnips, mangolds, and the other roots would be fed to them. The hogs were to be finished off with a little corn.

Beside hay and grain he calculated to sell 100 early fat lambs, 100 hogs of 240 lb. each, 100 fat ewes, 9 quarters of beef, and 3 hides, and argued that the meat products alone would bring him in $3,000, less the cost of 100 new ewes and 3 oxen. No doubt rutabagas and cabbages are fattening food, but they are uncertain crops, because they are liable to be injured by fungi, insects and worms. Much labor has to be expended in growing them, and they will not really succeed excepting on good moist land. The hot, dry American summer is much better adapted for the production of Indian corn than of Swedish turnips. Indian corn luxuriates in intense heat, while the most favorable conditions for turnip-growing are a low temperature, many rainy days, and a large amount of rain, as in Scotland. Beets need less rain, it is true, than turnips, and they are not so liable to be injured by insects, etc., but they must be well manured and carefully cultivated.

Influence of Roads on Farm Arrangements.

As has been said, it is often wellnigh impossible to distinguish accurately between chemical and mechanical conditions in studying this question of farms. Thus, the mere difference between good and bad roads, or between a rough and a smooth country, will often make a very material difference as to the kinds of crops grown, and of manure produced upon the farms, and so of course upon the mode of carrying on the farms. Even in Holland it is said that a peat-bog is of little or no value unless it can be brought into direct water communication with the system of canals which traverse the country in every direction; although when thus connected the bog may be worth $500 an acre, more or less according to the thickness of the peat. The chief and perhaps the only reason why so much of the high-lying peat-land in Holland is still unreclaimed is that such tracts are too far from any canal to admit of their being worked profitably at present. (Jenkins.)

Oxen and Horses contrasted.

In a smooth country provided with good roads, all the heavy

transportation and the farm operations will usually be performed by horses, since it would not be economical there to hire costly men to drive slow-moving oxen; while in a broken or boggy country oxen are almost absolutely essential for the practice of agricultural operations. The cloven hoof of the ox enables him to work on land so muddy that a horse could hardly traverse it. When sunk in adhesive mud, the solid hoof of the horse acts like a sucker; it can only be lifted by a powerful effort because the lifting tends to produce a vacuum under the hoof. But beneath the cleft hoof of the ox air can slip in with comparative ease when the hoof is lifted, and, other things being equal, the hoof of the ox will hardly sink in the mud so deeply, to begin with, because of the spread of the toes.

Oxen can be well maintained on much rougher forage than is needed by horses, while in respect to patience and fortitude the ox is greatly superior to the horse. If a wagon is "set" in a muddy road, or if any serious obstruction impede the draught, a horse, or a team of horses, will soon lose heart. Not only is the horse apt to fret himself unduly when thus troubled, but it usually happens, after the first trial or two have failed to overcome the impediment, that he becomes disheartened and practically useless. But a steady ox will try again and again, as often as the driver may care to urge him, or until the difficulty has been overcome. Captain Marcy, in passing from Utah to New Mexico over the Rocky Mountains, in winter, set out with horses, mules and oxen, the latter to be used as food. "I found," he says, "as soon as we struck snow three feet deep, that the mules directly became disheartened, lay down, and would not exert themselves. The horses seemed more ambitious, and would push their way through the snow as long as possible; but they soon became weary and gave out from exhaustion; while the oxen slowly and deliberately ploughed their way through the snow for a long time without becoming jaded." Moreover, the oxen subsisted better than the other animals on the pine boughs and browse which were their only food.

Oxen too clumsy for civilized Farms.

It may here be said that one reason why oxen are so little used nowadays in the smoother parts of New England, as compared with their abundance at earlier periods, seems to depend on the fact that oxen cannot so well be used as horses for hauling mowing-machines, hay-rakes, cultivators, and all the modern machin-

ery which makes farming possible in these parts. It is true, of course, that the bringing of beeves by rail from the West has lessened the value of cattle fattened here in New England, but it is evident enough that the desertion of many of the hill farms in New Hampshire must have depended in good part on the fact that horse implements cannot so readily be used upon those farms as elsewhere; that is to say, under the modern methods of farming, the rough hill farms are put at a still greater disadvantage than they were formerly. The introduction of machines for securing the hay-crop, in particular, has made it so much easier and cheaper to get hay from smooth land, that many of the rough farms can no longer compete with the smooth, even when the rough land is equally fertile with the smooth land, or even more so. Precisely the same thing is seen almost everywhere in New England on the rougher parts of smooth fields, where the mowing-machine cannot readily be driven. Many such spots are now left to be overgrown with weeds and bushes, which were formerly kept neat and clean by the scythemen; and the worst of it is, that such patches tend constantly to increase in size from one year to another, unless resolutely opposed.

According as oxen or horses are kept, the farmer will naturally grow different kinds of fodder. Even different grades of hay will be required, and on this account there will be a much stronger incentive to drain low-lying meadows on farms worked by horses. And in general the tillage, the crops, and the character of the dung-hill will differ because of the different modes of feeding and working the two kinds of animals.

In contrasting the horse and the ox in this way, special reference is had to this country and to England. But it is a fact that upon many parts of the continent of Europe the small farmers use cows, almost universally, as beasts of draught, precisely where the country is flat and the roads excellent. This exception does but enforce the argument, however, as to the influence of circumstances upon the conduct of farms. If the cottager can get a beast of draught that will not only plough his field and carry his produce to market, but at the same time yield some milk, the facts of smooth roads and easy tillage will influence him only in so far that they render the stark strength of the ox unnecessary. As for the gain in time to be had by using horses, that will have little significance where the amount of hard work of

any one kind to be done is small and infrequent. It may be said, in passing, that this practice of using cows as beasts of burden seems to be a commendable one for the conditions under which it occurs.

Under still other conditions, as in some parts of Italy and of India, the wellnigh amphibious buffalo is preferred to any other animal for agricultural operations, and even as a beast of burden. These animals are particularly well adapted for ploughing rice-fields, since they can work in mud that is knee-deep. At Sudashiapet, Mr. Mitford saw them working in this way, and noted that, when released, they could be seen "wallowing in the muddy pools, basking in the sun, with their backs covered with frogs"; and Haeckel, in his turn, when speaking of rice-fields and water-meadows in Ceylon, says, "In these fields, herds of black buffaloes lie half in the water, while graceful white herons pick insects off their backs."

Cotton, Jute, etc., versus Flax and Hemp.

With regard to textile materials, it may be said that the introduction in recent times of new kinds or species of fibres, has exerted almost as wide-reaching an influence on methods of farming as the invention of mill machinery for manufacturing the fibres into cloth had had upon the old domestic industries of spinning and weaving. Formerly, more or less flax and hemp were grown almost everywhere, while nowadays these crops have been relegated to special localities, because of the very general use in modern times of cloths and cordage made of cotton, jute, Manila hemp, and even of wire.

Another instance of the influence of external conditions upon the modes of farming may be seen in the Chinese practice of using human excrement as a manure. It has been remarked by several travellers, in explanation of the general use of this substance in China, that it may depend, not upon any intrinsic worth of this kind of manure, but upon the fact that comparatively few cattle are kept in that country. Manual labor is general throughout the empire; very few animals are used for cultivating the land, or kept for any purpose; and, besides, the Chinese are a nation of cottagers or small farmers, — a class more likely than any other to save every kind of manure that may come within reach.

Adaptation of Cattle to the Soil.

European observers have called attention to the harmony which is often seen to subsist between the character of the soil of a given locality and that of the cattle and other animals which are supported upon it. That is to say, the farms and the cattle are well adapted one to the other. In some of the wilder parts of France, for example, "Very few cattle are kept, and those few are not good; but they are as good as the land will support. Though bad milkers, they do very well upon the food they get, whereas better stock would starve. They give milk enough to rear their own calves. By adding cake or meal, a better result could be obtained, but it would not pay, since milk sells badly. Until recently, a little straw and some inferior hay was all that the stock could have during the winter; but with improved cultivation a supply of clover, lucern, sainfoin and maize, preserved for winter food, will permit some of the more enterprising farmers to use cattle in larger numbers and of more kindly habits."

Again, in the old French province of Marche, "the farmer depends for his money returns upon the produce of his sheep principally; they are reared without cost upon the rough, open pastures round each village; and in winter, when they must be kept under cover while the ground is covered with snow or deluged with rain, they are barely kept alive by rations of dried fern, or heath, or bad hay. Under this treatment, many hundreds die yearly, and those that survive give a worse return, both of wool and meat, than any other sheep in France: they are the smallest in the country, and the lowest in price. . . . The sort of animal is by no means a bad one; diminished in size by living in a bleak, cold country, and by being badly treated, it greatly and rapidly improves when moved to better quarters." (Richardson.)

Changes due to Railways and Steamships.

But the most striking instance of all is the change in the character of farms pretty much over the whole world, which has been brought about by the cheapening of transportation in recent years, particularly that of grain and cattle, from the Western States of America, and of grain from India. The invention of Bessemer steel, and the building of railways with it, improvements in the building of steamships and of compound engines to drive them, as well as the construction of grain elevators, and the carrying out of improved systems of organization, have practically changed

the scope, and plan, and attitude, so to say, of English farming in particular, and have undoubtedly considerably modified the farms of most other regions. These changes have given a very severe blow to what was technically known, formerly, as "high farming," when practised in the large way on farms of mixed cultivation, for nowadays transportation is so cheap that when produce has once been put into a ship or car, it costs but little more to move it 600 or 800 miles than it does to move it 100, and wild, cheap lands have a preponderating advantage over those of higher price which are nearer the markets, for the first cost of growing grain on the outlying land, or of rearing stock there, is extremely low. As illustrating the economy of transporting large quantities of produce to great distances, the story is told of a Western city where 50 cents has to be paid for moving a barrel of flour from the mill to the door of a dwelling-house, while only 35 cents more is required to land the barrel at Liverpool.

Formerly, before the existence of railways, the cost of land-carriage for no more than 200 miles might consume the whole value of a bushel of wheat. It is said that between the years 1860 and 1880 the cost of transporting grain fell from four cents per ton per mile to half a cent, while the production of wheat in the United States rose from 160 to 480 millions of bushels. In England and Wales, on the other hand, the production of wheat, which in 1840 was estimated at 108 million bushels, worth 155 million dollars, did not exceed, in the year 1890, one-half of the above given amount, and was not worth much more than a third of the old value. During the ten years, 1880 to 1890, the growth of wheat in England declined 30 per cent. (Caird.)

The Size of a Farm a Matter of Executive Power.

The sizes of farms, and sometimes their characters as well, are commonly determined in good part by the degree of superintendence required. Mere pasture farms are the largest. Next in size, as a general rule, are those composed of mixed pasture and tillage; then come arable farms, and so, through all conceivable degrees of diminution, down to the smallest garden.

High and Low Farming.

As is well known, there are two great classes of farms; viz. those based upon "*intensive*" culture, — "high farming," as the English call it, — and those based upon "*extensive*" culture. In the first class, large crops are produced at the expense of much

labor and capital; and in the second class, small crops are obtained at very small cost.

The distinction between the two kinds of farming has been mentioned already; but the subject is one that invites discussion, and much might be said upon it. The student will do well, at the start, to dismiss from his mind any conceptions which may have entered it, either to the effect that high farming is necessarily good farming, and to be striven for, or that extensive farming is necessarily bad farming. For neither of these opinions is tenable.

High farming may be good in one place and very bad in another, and the same remark is true of low farming. Everything depends upon the situation of the farm with regard to the rest of the world. There are very few places indeed, if there be any, of which it can be said with truth that good farming consists in getting the largest possible yield from a given piece of land. There are still many districts in this country where labor can be used to much better advantage by applying it to the cultivation of larger parcels of land than by employing it for saving or hauling out manure to be used upon smaller parcels.

What is Good Farming?

The true definition of good farming, and it is one that will apply everywhere, is that it consists in getting the highest possible profit from the land, year in and year out. As a general rule, the true aim of the farmer is not to bring his land up to a high pitch of productiveness, but to make the best possible use of the ways and means at his disposal. "It is a very old opinion that the successful farmer is he who, with skill and knowledge of general principles, most clearly recognizes the particular facts and circumstances under which his farm is placed, and applies his skill and knowledge to them accordingly." (Bence Jones.)

Formerly, in case manure was costly and labor cheap, it may sometimes have been well to till the land carefully. But when labor is costly as well as manure, it will often be the best policy to do away with labor, in so far as may be practicable, and to throw one's self upon the natural forces of the land. There must always be numberless situations to which the maxim of the Roman farmers, "nothing is less profitable than very high cultivation," is directly applicable.

In describing some patches of wheat-land near Cawnpore, in

India, irrigated by manual labor, Caird remarks that "The produce of wheat is about 16 bushels an acre,—little more than half an English crop. On such land, with water, light and heat in abundance, the crop might be doubled by an application of nitrate of soda, but at the respective values here of wheat and nitrate there would be little profit. Nitrate of soda would pay [here] on suitable land with wheat at 6 shillings a bushel, but would leave no profit on wheat at 3 shillings. [At this time], Nov., 1878, wheat is selling in the market [here] at the unusually high rate of 4 shillings the bushel of 60 lb."

There is a saying in the County of Meath, in Ireland, that the excellent grazing lands of the locality need no other labor than that of "a man and a dog to a thousand acres."

Manifestly, the definition of good farming above given will include even that kind of practice in which the soil yields only a minimum crop, providing the cost of growing, collecting, and marketing that crop is sufficiently small. It was another Roman maxim that "Those profits are to be preferred which cost the least."

Examples of Low Farming.

Practically, there can be no shadow of doubt that systems of extensive farming are often the best possible systems for the conditions under which they are practised. The farming customs of many uncivilized tribes well illustrate this point. For example, Mr. Hunter, in his description of the Indian province Orissa, says: "The Governor told me that, as he is anxious to extend cultivation, he asks no rent from any jungle tribe that will settle down. They may cut down as much forest as they choose, and cultivate the clearing as long as they please. But all his efforts have failed to induce the nomadic tribes to submit to the toil of permanent husbandry. They willingly burn a patch of jungle, but avoid the chance of any question of rent arising by deserting their clearing every third year. This practice simply means that, where land is to be had for the clearing, it pays better to take a rapid succession of exhausting crops off the virgin soil, than to adopt the laborious processes of regular cultivation. The forest tribes show great talent in making a livelihood with the minimum of labor, and this is one of the ways in which they solve the problem."

Another, and evidently a better account of the matter, is given

in Captain Forbes's "Travels in Burma": "The great peculiarity of all the 'hill tribes' of India is their unsettled and ever-changing mode of life. They are all 'nomadic cultivators.' To raise their scanty crops, the virgin forests on the steep slopes of the hills must be cleared and burnt; but the excessive rainfall soon washes the friable soil off the surface, so that only one or two crops can be raised on the same spot until it has again been allowed to become overgrown with jungle, and a fresh deposit of earth has formed. This system of agriculture naturally requires a large extent of country. It is not every hillside that is favorable for cultivation; consequently in two or three years all the culturable patches near a large village become exhausted, and the whole community must move off to new localities, perhaps thirty or forty miles away, since they may not trespass on what is regarded as the range of another village. Hard and bitter, indeed, is the struggle for life of these hill men. Every year the dense forest must be attacked, and with infinite labor large trees six feet in girth and 100 to 150 feet or more in height, have to be felled, cut up, and burnt, to clear the ground. And then fences have to be made to keep out wild hogs, deer, and elephants." In Burma the usual crops are hill rice, maize, roots, and greens, with enough cotton for domestic use.

Another instance of extreme extension is seen in the old Spanish ranches of California and Texas, where great droves of cattle were herded from place to place, according to the state of the grass. At one time the only merchantable products of these ranches were hides, horns, and tallow. It is a great merit of cattle-farming in outlying regions that the animals can transport themselves to or towards the market. The sheep-farms of Australia and New Zealand exhibit the same things; much land, little labor, and no very great amount of capital being devoted to the production of wool, skins, and tallow. Indeed, nothing but poor pasturage can be hoped for in those parts of the world where the annual rainfall is insufficient for the requirements of a more intensive agriculture. Unless water for irrigation can be brought from some distant source, such regions must always be given over to pastoral rather than to agricultural pursuits.

Many of the moorlands and heaths of Europe are in pretty much the same category, and so are those brush farms of New England where the land is burned over once in a good many years,

and a crop or two grown upon the ashes. Wherever land is cropped for a year or two, or for any small number of years, and then left fallow, the agriculture is of course extensive, and this state of things will usually be found wherever land is cheap and labor costly, where the means of transportion are limited and money scarce.

Mr. Seebohm, writing at Ust-Zylma, in Siberia, a town some hundreds of miles east by north from Archangel, says the cattle are fed principally upon hay, which is cut upon low lands on the river's bank. These lands are flooded every spring, and any manure placed upon them in winter would speedily be washed off; nor is it needed, as the river itself is the great fertilizer in these low-lying districts, just as the Nile is in Egypt. The winter is long, and the length of time during which the cattle are stall fed so great, and the amount of upland available for cultivation so small, that there is always a large surplus of manure, which the peasants do not think worth the cost of preservation. So much manure is allowed to accumulate in the streets that the town is one vast dung-hill, until the refuse is washed away at the time of the spring thaw, when the river overflows its banks.

Many of our Western wheat-fields afford admirable examples of extensive farming. The value of the crops obtained from each acre of the land often seems absurdly small, and over wide areas the crops may not be equal in amount, on the average, to as much as one-third of what is usually harvested in Great Britain; and yet the Western land is so cheap, and the cost of growing grain upon it is so small, as well as the cost of transporting the grain, as has been said, that the prairie farmer finds a margin of profit wide enough to enable him practically to overcome those competitors who try to make money by growing grain intensively.

It is to be noted that the cost of producing the grain is diminished, not only by the use of machines for harvesting, threshing, etc., but that the land is ploughed rapidly and not deeply. It is said that on some of the great wheat-farms of the West the furrows are habitually drawn to a depth of hardly more than 2 inches. Throughout the United States, a furrow depth of 3 or 4 inches for wheat is doubtless more common than a depth of 5 or 6 inches, while a depth of 8 or 9 inches must be regarded as exceptional. (Oetken.)

In all wild or new countries, extensive farming is in some sort a

necessity of the case. For land is worth so little in those regions that it is cheaper to use a great deal of it to produce a given effect, than it would be to obtain this effect upon less land by means of dung and tillage. It is rational and advisable in such cases to rely more upon the natural forces which are close at hand, than upon human appliances, such as labor and capital. It does not necessarily follow that poor land will always be cultivated extensively, though it is usually. The sand-dunes of Spain and Holland, mentioned on pages 75 and 76 of Vol. I, are exceptions to the rule, and so are some farms in the Belgian Campine, when irrigated and fertilized, as described on a previous page.

Grass-Farming usually Low Farming.

Almost all systems of farming which depend upon the production of hay or grass are extensive, though some of the modern systems, in which grass forms one step in an otherwise intensive rotation, should be excepted; as well as some of the systems based upon the feeding of cattle with cut green fodder exclusively.

Sometimes, however, the climate of a locality forces the farmers to practise grass-farming even on fertile soils. Thus, in Ireland, where the air and soil are almost constantly moist, grass grows uncommonly freely, and it often continues to grow through the larger part of the winter, while grain is apt to fail for the very reason which makes the grass succeed. In a climate such as this, the highest profit can be got from the land by keeping it constantly in grass; or tilling it only with the view of helping the grass, or of growing other forage crops, such as turnips, for example, to supplement the grass, or, perhaps, for the purpose of supplying a part of the food consumed by the farmer's family. In order to work in this way, the farmer will of course need to have capital enough to buy animals to stock the land.

The climate of Ireland is so extremely moist that even oats — the chief grain-crop of the island — do not produce so many bushels to the acre, under good farming, as are constantly obtained in Scotland. It is said that, as a general rule, only the coarsest kinds of oats are grown in Ireland, and that these inferior varieties succeed there much better than the improved sorts. The trouble is, that there is too much moisture and too little sunshine to ripen a really heavy crop of grain, except in chance seasons.

Of the South of Ireland, especially, it is said that wheat ripens

with difficulty, that the crop is often inferior, and that the yield of grain is more dependent on the character of the season than in most other countries. There is small use, withal, in manuring for wheat, or in trying to grow this crop in rotation with turnips, as is done in England, for the richer the land is made, so much the more freely does the wheat run to straw, and so much the lighter is the grain that is produced.

According to Bence Jones, the scantily-manured wheat of an Irish peasant will usually yield more grain than is got by his more ambitious neighbors, operating perhaps on contiguous fields, because on an average season there will be sunshine enough to ripen tolerably the peasant's thin, short-strawed crop; while the ears of free-growing wheat, on highly manured land, will not be half filled, and much of the grain in them will be fit only for chicken-food.

Low Farming requires much Land.

There are, of course, all shades and degrees of farms between those which are purely extensive and those which are really gardens, so intensively are they cultivated. But as regards extensive farming, it is easy to conceive of conditions under which it will be best to keep the element of labor, whether of man or beast, as low as may be practicable; to avoid, as far as possible, all crops that require much cultivation; to send the cattle into the field in the early spring, and to keep them out as late in the autumn as may be consistent with their welfare; — and to this end a large farm, i. e. a great deal of land, is essential.

There is less sense than would appear at first sight in much of the talk against large farms that fills our New England newspapers. Where due attention is paid to the conditions which control the disposition and conduct of a farm, the size of it is a matter to be regulated solely by the administrative power and business faculty of the person who works it, and the amount of capital at his disposal. In any given locality, it is the cost of labor which controls the profit to be gained by any agricultural operation. A noted French writer upon agriculture, Moll, argued long ago that the chief error in the agriculture of his own country, even, was the employment of too much labor; more, he said, than the mediocre fertility of the land would justify. It was to this cause, among others, that he attributed — even before the days of American competition — the decline of large farms in France; the com-

paratively costly hired labor of the great farms could not compete with the family labor of peasant proprietors.

One point to be noticed is, that in many regions farms are so arranged that large numbers of laborers have to be called in at certain seasons in order to secure the crops. Formerly — before the general use of machines for securing hay and grain — it could be said, even more emphatically than can be said now, that there were numberless localities where the fixed population was not large enough to harvest the crops that were grown upon the land. In most regions where large farms were cultivated, migrations of laborers from outlying districts towards these farms occurred every year, at the time of harvest. Thus, Belgians swarmed into some parts of France, Irish into England, hill men into the plains of Italy, and Londoners to the hop-fields of southeastern England. But for the help afforded by these strangers the farms could not have been cultivated as they were. Hence the conclusion that the state of population of a country may be of paramount importance in the arranging of the farms. The absence of laborers may absolutely forbid the growing of some kinds of crops, and compel the farmer to devote himself to other methods of cultivation.

Localities fit for High Farming.

It is on rich soils, and upon tolerably good soils near a quick market, i. e. either in the vicinity of densely-populated places, or where, from a favorable climate, or some other peculiar circumstance, some special crop can be made to prosper, that intensive farming finds its place. Unnatural examples of it are seen in localities where the granting of bounties by governments has encouraged the growing of sugar-beets, flax, hemp, or the like. In the Champagne wine region, in some of our own tobacco districts, and upon the Cuban sugar plantations, high farming pays, though it is not always practised. It is seen at its best in England, Scotland, Belgium, and Saxony, where good land, abundant capital, and dense populations are coincident. It would be palpably absurd to practise the Flemish garden husbandry in a sparsely-settled country, far from any great centre of population. But, wherever other things are anywhere near equal, farmers in the vicinity of towns and cities must necessarily have a certain advantage over distant competitors in respect to the growing of some kinds of vegetables which they alone can supply to consumers in perfect condition and in a state of fresh and natural ripeness.

European writers tell of farms in some parts of France, and in the mountainous regions of Germany, where the labor of 3 men and 2 horses is sufficient for 250 acres of land, while in the market gardens around Paris the labor of 700 men and 120 horses is expended on that amount of land. But in both instances the farming is excellent.

Caird has called attention to the fact that in England the maximum of fertility of land in its natural state is seen in certain rich pastures which are capable of fattening an ox and two sheep on an acre. Such soils are exceptional, though met with in most counties. He cites the Pawlet Hams in Somersetshire, which is a tract of rich alluvial soil on the river Parrott, stretching along the seaboard. It is in permanent pasture, and lets for $25 or $30 the acre for grazing. Some of the marsh-lands of Sussex and Kent are of equal value. The minimum of fertility he exemplifies by a bleak mountain pasture, where ten acres will barely maintain one small sheep. He adds that the artificial maximum and minimum of fertility which result from the treatment of soils of the same quality may be illustrated by taking two of the experiments of Lawes and Gilbert, in which the average crops of the last twelve years out of thirty were as follows: —

	Grain. lb.	Straw. lb.	Total. lb.
Wheat, average of last 12 years, no manure	730	1,120	1,850
" " " " with special manure	2,342	4,928	7,270

The soils were similar, strong land on clay, with chalk below; the management was the same, and all the other circumstances. The only difference was that there was no manure for thirty years in the one case, and an abundance of manure in the other. Three times as much grain, and four times as much straw, were got by the expenditure of an amount of manure which gave a profit of 100 per cent.

English writers have computed that an acre of first-rate permanent grazing land, carrying an ox of moderate size and two sheep, will produce each year some 200 lb. of beef, 20 lb. of mutton and 5 lb. of wool; while if the same land were subjected to tillage it would yield 12 long tons of potatoes or 40 bushels of wheat every alternate year.

Few Farms are purely Extensive.

In reality comparatively few farms can be found every acre of which is cultivated intensively, and there are hardly any farms

that are wholly destitute of patches of garden ground, devoted to what, for the sake of contrast, may be called high farming. The true rule in every case is that that style of farming should predominate which yields permanently the largest profit. It is quite right withal that there should be a marked contrast between the main body of a farm cultivated extensively, and the garden patches upon it. All the manure which is to be had upon such a farm should be devoted to the dressing of a comparatively small area of the best land. It is usually better in such cases to manure 10 acres of land thoroughly, than 20 acres insufficiently; for by the former plan only about half the labor that would be required by the latter will be expended.

This is the argument to apply to our New England conditions. Instead of joining in the common cry in favor of smaller farms, it will be well to urge careful cultivation of the best portions of the existing farms, and an extensive treatment of the remainder. Much good might be done, no doubt, at small cost, by taking pains to improve bog meadows, and those old pastures which are capable of improvement, and by favoring the growth of wood upon those portions of the land which are worthless for other crops; but, speaking in general terms, it is not likely that the character of the agriculture of this section will undergo any very material changes for a long time to come.

It is not easy at any time to change the husbandry of a section of country, or of a farm, all at once, from extensive to intensive. Excepting the cases where land may be drained or irrigated, much time and patience are required to bring up poor land to a medium state of fertility, even when the physical conditions are favorable. But that even the poorest land can after a while be made fertile is well shown in the gardens about dwelling-houses. It has been often remarked in Northern Europe that, if one were to judge of the land of a district by the luxuriant vegetation around the farm-houses, he would usually be grossly deceived. The gardens are constantly receiving fertilizing materials, both intentionally and without forethought. The refuse that falls from a house, in the course of generations, is of itself sufficient to fertilize an appreciable patch of desert, provided only that the climate is moist enough to keep the land from drying out, and that poultry are kept away from it.

Moisture essential to Fertility.

It would be idle, however, without control of water, to expect heavy crops from poor land, or to apply forcing manures to such land in the hope of great profit. No land can be made to pass for more than it is worth, or to do better than it can. For each and every kind of land there is some one best possible rate of applying manure, and the rate for poor land is very different from that for rich land. It is precisely this consideration that naturally leads the farmer to devote his energies to the best lands upon his estate, and to let the poorest lands remain as wood or pasture. "The most profitable and productive soil is that which is at once fertile and easy of cultivation. A rich loam which yields a ton of wheat to the acre is less costly in labor than a poor clay which yields little more than half that weight." (Caird.) The argument in favor of intensive culture upon a small portion of an "extensive" farm is a mere continuation of the same general idea.

The Character of a Farm not to be changed all at once.

The true way of changing from "extensive" to "intensive" culture would be gradually to enlarge the amount of land upon the farm that is cultivated intensively, i. e. as fast as the thing could be done profitably. There is one reason why this change should not be made rapidly upon any single farm which is often lost sight of by amateur farmers, and that is the fact that it is rarely worth while (from the commercial point of view) to make a single farm very much better than the farms which surround it. The price of every farm, no matter how good the farm may be, is largely dependent upon the price of the neighboring farms. No rapid improvements in the quality of a farm can be made except at considerable cost. But the capital expended could hardly be recovered on selling the farm, unless the neighboring farmers had at the same time improved the character of their possessions.

The more intelligent and appreciative the man might be who proposed to buy the improved farm and settle in this supposed neighborhood, so much the more likely would he be to argue "what man has done, man can do." He would probably rather buy one of the poor farms and seek to improve it, than to purchase the property which had been improved already.

It is not to be understood that the argument is directed against the improvement. It is urged only that changes must be gradual

to be healthy, and that no one man can all at once alter the habits and customs, and the standard of value, of his neighborhood.

Contrast between Cost of Grain-crops on Good Land and on Poor.

The following computation as to the comparative cost of growing wheat when feebly or fully manured, has been translated very freely from the French of Malaguti and Lecouteux. It may serve to illustrate the proposition that labor may usually be expended to much better advantage upon good land than upon poor land, and that, as a mere extension of the same idea, it is more profitable to manure a small field generously than a large one insufficiently.

Starting with a two-acre field, the idea is to manure the land in such a way that the wheat-crop (when its turn comes in the rotation) shall absorb 10,000 lb. of manure from one half the field and 20,000 lb. from the other half. It is admitted for the sake of the argument, that every 10 lb. of manure absorbed by the crop stand for a yield of 1 lb. of wheat, so that the manure on the lightly-manured half of the field will give a crop of 1,000 lb., or say 17 bushels, of wheat; and that upon the other half will give 2,000 lb., or say 34 bushels. It is admitted furthermore, that the manure costs 10 cents the 100 lb., so that the 1,000 lb. of grain (due to the 10,000 lb. of manure), will have cost $10, on account of the manure, and the 20,000 lb. of grain will have cost $20.

But the cost of a crop does not depend alone upon that of the manure. There are a number of other items to be taken into the account, such as labor ($5.50 for one half the field and $7.50 for the other half), seed ($2 the acre), ground rent, wear and tear of implements, taxes, and interest on the capital employed (say $3 the acre for all these items); and the sum of these expenses added to the cost of the manure will raise to $1.20 the cost of each bushel of wheat harvested on the lightly manured half of the field, while the cost of each bushel of grain harvested on the richly manured land will be $0.95.

Reckoning the straw as worth $5 the ton, and that there are 100 lb. of it for each bushel of wheat, the cost of the bushel of grain will be reduced to $0.96 on the lightly-manured land, and to $0.71 on the land which was generously manured.

Finally, if the wheat is sold at $1 the bushel, and the straw at $5 the ton, the profit, in round numbers, from the acre that was lightly manured will be $0.75, and the profit from the acre that was heavily manured will be $10.

A prominent farmer in the district of Brie, in France, who is said to practise high farming in a skilful way, has stated that he could afford to sell wheat at $1.13 the bushel when the yield is 40 bushels to the acre; at $1.33, when it is 34 bushels; and at $1.60, when it is 28 bushels. Manifestly, there might be a decided advantage in cultivating this crop intensively on that farm were it not for the competition of American wheat, which was said at the time to have cost about $1.12 the bushel when landed in France.

It is to be observed that, while the foregoing comparison may illustrate well enough the significance of manuring for wheat under certain conditions, the actual figures given differ widely from those applicable to wheat-growing, as practised here in America on unfertilized land. Among many different statements which have been published in this country, those estimates which put the cost of wheat at 70 or 75 cents the bushel are thought to be liberal, while the contention of some Westerners that, under favorable conditions, wheat may cost the farmer no more than 30 cents the bushel, have hardly been generally credited as yet.

Cost and Yield of Crops of Maize.

The same reasoning will apply forcibly to the growing of Indian corn. As long ago as 1841, Mr. Colman, in his 4th report on the Agriculture of Massachusetts, page 20, gave estimates of the cost of cultivating an acre of corn in the Connecticut Valley, one of which was essentially as follows: —

Preparatory ploughing and harrowing	$5.00
Five cords of farmyard-manure	12.00
Carting the manure and putting it in the hills	4.00
Seed and planting	1.75
Cultivating and hoeing	5.00
Gathering and husking	5.00
Interest on land, and taxes	6.00
	$39.25
The crop was 40 bushels of shelled corn, — and stalks (stover) estimated to be equal in value to 1 ton of hay	10.00*
Actual cost of 40 bushels of corn	$29.25
Actual cost of 1 bushel of corn	0.73

Mr. Colman remarks that "The judgment of some of the most

* According to the usual allowance, that 100 lb. of stover are harvested for each bushel of shelled corn, there would have been 2 tons of stalks in this case, worth, according to the present manner of estimating, some $16 to $20, which would reduce the cost of the corn to the neighborhood of 50 cents the bushel.

intelligent farmers of this vicinity places the average yield of corn at 85 bushels to the acre."

In contrast with the foregoing may be cited a crop of corn grown on 9½ acres of land, by Mr. E. F. Bowditch of Framingham, in 1875.* The round figures given in the table, as obtained by reducing to one acre Mr. Bowditch's estimate of the entire crop, are not literally correct, since they indicate that his crop cost rather more than was actually the case. They are given here merely for the sake of comparison.

Preparatory ploughing and harrowing	$5.00
Fertilizers, viz. 462 lb. of sulphate of ammonia, 177 lb. of muriate of potash, and 163 lb. of bone-black treated with 81 lb. of sulphuric acid	33.00
Mixing, carting and spreading fertilizers	1.40
Seed and planting	1.60
Cultivating and hoeing	5.00
Cutting and stooking	3.00
Husking	11.50
Stowing the stover	7.50
Interest on land, and taxes	5.50
	$73.50
Beside the corn, there was harvested 5.75 tons of stover, which was reckoned to be worth $8 per ton	46.00
So that the actual cost of the 115.5 bushels of shelled corn obtained was	27.50
And the actual cost of one bushel of corn was	0.24 †

This large crop had grown upon grass-sod which had had no manure for three years, and which had been ploughed under, seven inches deep, in the autumn of 1874. The soil was a dark-colored loam, upon a sandy clay subsoil. One-half of the mixture of fertilizers was spread broadcast in the spring of 1875, and the other half strewn in the drills and covered with the foot before the seed-corn was dropped by hand. The forcing effect of the large dressing of sulphate of ammonia is manifest.

Cost of Crops of Roots and Potatoes when Well or Poorly Fed.

In respect to root-crops, the contrast between proper and improper manuring can be shown even more emphatically, perhaps, than with grain-crops, for it is manifest that the labor expended in cultivating and harvesting large roots must be proportionally

* Abstract of Returns of Massachusetts Agricultural Societies, 1875, p. 140.

† Mr. Bowditch's more precise figures give 22.4 cents as the cost of one bushel of the corn.

small. Five tons of turnips waiting to be lifted from one acre of land will commend themselves more than a considerably larger quantity scattered over three acres. Of the two crops of potatoes contrasted in the following table, the smaller is copied, with modifications, from one of Mr. Colman's examples of the cost of growing this crop in Middlesex County, Mass., and the larger is a crop grown by Mr. David Whiton, of Hingham, in 1874. The figures all relate to one acre of land.

OUTLAY.

	Colman.	Whiton.
Preparatory ploughing and harrowing . .	$6.50	$8.00
Manure	16.00*	71.00†
Seed and planting	7.30	30.50
Cultivating and hoeing	5.00	18.00
Digging, &c.	5.00	30.00
INCOME.		
In Colman's case, 150 bushels of potatoes were harvested, worth, say 50 cents the bushel	$75.00	
In Mr. Whiton's case, 461.33 bushels were obtained, the potatoes being "very smooth and very even throughout the piece"		$230.50

As a matter of course, such reasoning as the foregoing can only apply to fairly good land, for, as every one knows, there is a limit beyond which no profit can be gained by manuring more heavily. The matter has been well stated by Lawes in the following terms: "Many of the charges connected with farming are much the same, whatever may be the value of the crops grown. Of course it costs something more to harvest a large crop of grain than a small crop, and the expenses on a heavy crop of roots will be somewhat greater than on a light one. Still, it may be said with truth that, with the exception of the money paid for manure to grow the larger crops, the charges remain very much the same, no matter whether the amount and value of the produce is large or small. Hence,

* Eighteen loads of barnyard-manure, of which 12 loads were spread, and six loads were put in the hills.

† Mr. Whiton's potatoes were grown upon dark-colored, gravelly loam, which was in grass, without manure, in 1872, and in 1873 also until August 1, when it was ploughed 10 inches deep and dressed with 420 bushels of manure from a barn-cellar for millet, which yielded two tons of hay. In April, 1874, four tons of rockweed were ploughed in 7 inches deep. After harrowing the land, furrows were drawn, and 600 bushels of barn-cellar manure were spread in them. After planting the seed-potatoes, a small handful of phosphate (600 lb. in all) was scattered over each set. It will be noticed that the land was left highly charged with manure for the use of succeeding crops.

if the increase of produce did but stand in a constant proportion to the amount of manure applied, that is to say, if the application of two or three times as much manure would but double or treble the crop, then high and ever higher farming would be a remedy for low prices."

There is no need to insist how narrow the scope of this reasoning is. The moment a certain limit is passed, the cost of the manure required to bring a given amount of gain increases much more rapidly than the proportion of the fixed expenses diminishes; and there is always a risk when excessively heavy dressings of manure are applied that the season may turn out to be unfit for the crops to make use of the manure, or even that the crops may be injured by it. Nevertheless, Gasparin's "Law of Manuring" — on which, as he said, the success of any rich and energetic cultivation must depend — will remain true of gardens and of farms which are cultivated like gardens. This rule was simply, "Manure to the maximum every plant that you cultivate." That is to say, apply such a quantity and kind of manure that, barring accidents, there shall be produced the largest crop which the soil and climate are capable of producing.

Highly interesting results have been obtained by Lawes and Gilbert in experiments made to test the utility of employing large quantities of ammonia salts in conjunction with mineral fertilizers. Every year, during many successive years, plots of wheat-land were manured alike with a mixture of the minerals, but salts of ammonium were added at different rates, viz., in such quantities that one plot got 200 lb. to the acre, and so received 43 lb. of nitrogen, another plot got 400 lb. of the ammonium salts, or 86 lb. of nitrogen, and another 600 lb. of ammonium salts and 129 lb. of nitrogen.

To yet another plot such large quantities (800 lb. to the acre) of ammonium salts were added that the land received each year 172 lb. of nitrogen. But, after 12 years' experience, it appeared that so small an increase of crops was obtained — even in extremely productive seasons — over that got by 129 lb. of nitrogen, that this particular experiment was no longer persisted in.

The results of the other trials are set forth in the following table, which gives the average yield in bushels of dressed wheat during periods of eight years.

Bushels of Wheat obtained annually, during the	From Mixed Minerals alone.	From Minerals and Ammonium Salts. 43 lb. Nitrogen.	86 lb. Nitrogen.	129 lb. Nitrogen.
8 years, 1852–59 . .	19.00	27.88	35.50	36.88
8 years, 1860–67 . .	15.25	26.25	36.25	39.75
8 years, 1868–75 . .	14.00	22.00	31.00	36.00
8 years, 1876–83 . .	12.63	20.37	28.00	36.25
32 years, 1852–83 . .	15.25	24.13	32.75	36.25
32 years. Total produce (grain and straw) lb.	2,421	4,029	5,845	6,832

The increase of wheat obtained by means of 43 lb. of nitrogen varied from 8 to 11 bushels, being not quite 9 bushels per annum for the whole period, and the application of an additional 43 lb. of nitrogen again increased the yield of wheat by between 8 and 9 bushels over the whole period. But the addition of yet another 43 lb. of nitrogen proved to be far less effective, the increase got from it being only 3.5 bushels per acre, and it was evident that in this case more nitrogen had been put upon the land than the crops could make use of.

Even in the year (1863) which was most favorable for the growth of wheat, when the crop which received 86 lb. of nitrogen yielded 53.5 bushels of grain, the crop dressed with 129 lb. of nitrogen yielded only 2 bushels more. Under the conditions then obtaining in England, it appeared that the crop got by means of 86 lb. of nitrogen had reached, if it had not exceeded, the profitable limit of growth. As regards the use of 172 lb. of nitrogen to the acre, it is to be said that only extremely rarely is a crop of wheat grown large enough to remove one half of this quantity of nitrogen.

It needs to be said, however, as Thorold Rogers has pointed out, that in respect to forage plants, no one has yet discovered how large a crop might be grown under favorable conditions. Very little is known, moreover, as to the economic limit beyond which it would be unwise to apply manure for the growth of mere forage. I have myself seen extremely heavy crops of timothy grown on land well situated as regards moisture, by freely top-dressing the grass in the spring with rich cow-manure, though, of course, the farmer ran no small risk of loss through unfavorable weather. The heavy grass might easily have been 'lodged' by beating rains, or have suffered damage in case foul weather had set in at the time of harvest. Rogers cites the experience of a friend who kept a very large quantity of stock and occupied a farm of 50

acres of light gravelly soil. His custom was to dig trenches 2 or 3 feet deep, and 4 feet apart, in his fields in the autumn, to fill the trenches with good manure and to level off the land. In the spring the land was sown with ray-grass and vetches. "The growth was so rank that when I went to see it as it was being fed to sheep, it almost reached to the top of the hat of a man who was six feet high, and the ground grew more than 20 tons to the acre of green food. He told me that the husbandry paid him well." It will be noticed that for forage which is to be fed out green, the risk of damage from the weather is somewhat less than it would be in the previous case of timothy which was made into hay. Rogers says further, "The sewage farm of Croydon is an area of 600 acres, a light and not otherwise fertile gravel. But being irrigated by the drainage, the fertilizing powers of which it completely exhausts, and discharges as mere water, it will grow for 10 months in the year an average monthly crop of ray-grass at the rate of 7 tons to the acre. After a time the sewage is shut off from some portions and oats sown on the land. Of these the land commonly yields a good 100 bushels to the acre."

Farming of Pioneers.

It often happens, when a country is first settled, that the inhabitants gain money by lumbering, or fishing, or even by hunting, and that the farms are made to depend almost entirely upon the natural forces of the soil, i. e. crops are grown without manure, and cattle are maintained upon wild pastures and upon the hay of bog-meadows, prairies, or salt-marshes. If the country is broken and hilly, or if its soil is poor, pasturing or lumbering in one form or another may forever continue to be the prevailing occupations, as is seen to-day in the Tyrol, in Switzerland, Norway, Sweden, Canada, Maine, and New Hampshire.

It may be said of this primitive husbandry, that, if uncontrolled fires could be prevented, land devoted solely to wood and to pasturage, and so protected from being washed away by rains, would not deteriorate so rapidly as is the case in some of the better defined systems of extensive farming. Trees, in particular, obtain their food at comparatively great depths and from wide distances, and are consequently less apt to exhaust the soil than crops which act more superficially; many of them get nitrogen also by the aid of micro-organisms growing on their roots, as has been explained in the chapter on Symbiosis. It is well to consider what large

amounts of produce are obtained from the land by fruit-trees in various parts of the world, — i. e. by apples, pears, plums, peaches, apricots, olives, chestnuts, oranges, lemons, walnuts, dates, etc., — and to reflect how small a proportion of manure is expended upon these crops. It is only with the advent of methods of farming which leave much land bare, or where crops are continually carried off from the land without any compensation, that the soil need begin to suffer much.

It is noticeable that, generally speaking, the gross product of woodland is less than is obtained when the same land is devoted to agricultural crops. According to Boussingault, a forest in the Vosges produces annually some 3,000 lb. of dry wood to the acre; while, taking one year with another, the same soil would yield of dry products to the acre, if it were devoted to

Wheat (and straw)	3,500 lb.
Hay	3,900 "
Clover or lucern	4,500 "

Excepting fertile prairie countries, it has not usually happened that any very abrupt or sudden transition from the condition of woodland or of pasture to that of arable land has occurred. On the contrary, the two systems of husbandry ordinarily shade into one another by insensible degrees. The earlier settlers till a portion of the pasture or the woodland for a few years, until it begins to run out, and then they leave the land to itself for a term of years, during which it reverts to grass or to wood, as the case may be. This system in its turn gradually changes to one of rotations, in which bare fallows are numerous, and these fallows, in European experience, have come to be fertilized in due course; at first by folded sheep, and then by farmyard-manure.

Virgin Soils.

To most Americans it is a fact familiar through personal experience, as well as from tradition and history, that when the forests and prairies of this country were first brought into cultivation, the land was, generally speaking, found to be much more fertile than it is now after it has been subjected to long-continued, careless cropping, or to continuous cropping without any help from manures. It is evident enough, even to the most superficial observation, that there must have been in the beginning a reservoir of fertility which has been not actually emptied in the course of years, but drawn upon and drawn down to a very considerable extent.

The explanation of the matter is not far to seek now that it has been made plain that forests and prairies in their natural state have the power both to bring up plant-food from the soil below, and to bring in nitrogen from the air. By depositing these things at the surface of the soil in the form of leaves and twigs and roots, they cover the land finally with a layer of very fertile earth. All this has long been plain to observation. It was illustrated by Voelcker's analyses of prairie soils, brought to England from America by Caird, which were found to be extremely rich in nitrogen, and is explained by Hellriegel's discovery of the nitrogen-bringing power of certain micro-organisms which live on the roots of plants.

Good Land depreciates but slowly by Cropping.

The experiments of Lawes and Gilbert have taught a highly instructive lesson as to the slow rate of exhaustion of really good land when cropped continually with grain without being manured. During half a century they have grown wheat incessantly without manure, upon what was originally good wheat-land, and during all this period the crops have fallen off at the rate of from 0.25 to 0.33 of a bushel to the acre each year. On land that had received no manure for 52 years, the average annual produce was about 13.75 bushels of dressed wheat per acre, which is a quantity distinctly larger than the average produce of the wheat-producing countries of the world, which is something like 12.25 bushels to the acre.

The diminution of fertility above mentioned has been found to depend almost wholly on the gradual using up of the nitrogen that was originally stored in the soil, the land having finally got into such poor condition that the uppermost soil taken to a depth of 9 inches contained no more than 0.1 % of nitrogen.

It will be noted that although a third of a bushel of grain to the acre may seem no great matter when only a single year is looked at, this rate of diminution would, at the end of thirty years, reduce the proper yield of the land to the extent of a dozen bushels, which is a quantity well worth manuring for.

Analyses made from time to time of the soil which received no manure and of that dressed with mixed mineral fertilizers, showed that, with the course of years, large quantities of organic nitrogen were lost in both cases, but particularly from the land which was dressed with the minerals. Here a loss of about 1,000 lb. to the

acre was noted in the course of the experiments. Lawes and Gilbert reckon that of the 28 to 32 lb. of nitrogen to the acre which becomes available for crops each year, as nitrates, upon their fields, about two-thirds are taken up by the wheat-crop, while one-third is lost in the drainage water. They observed that rather more nitrates were formed in the soils which were dressed with minerals than on unmanured land, and that in consequence both the crop and the waste of nitrogen were slightly increased. In a similar way, as they urge, the application of mineral fertilizers to new land may frequently increase the wheat-crop to a notable extent, because in soils naturally rich in organic matter nitrification may be promoted by the application of phosphates and potash.

So too in their experiments on continuous grass-growing, there was obtained from unmanured land an average crop of 2,531 lb. of hay per year and per acre during the first term of 10 years, and 2,236 lb. during the second 10 years, i. e. 2,383 lb. during the full period of 20 years. The average annual decline in yield during the second 10 years, as compared with the first, amounted to nearly 300 lb. of hay, to rather more than 4 lb. of nitrogen, and to about 22.5 lb. of mineral matter.

Causes of "Improved" Farming.

Although, theoretically speaking, it might be possible to keep land in good heart by either of the methods of farming above cited, provided only the land were left at rest during sufficiently long periods, and were protected from fire, and from washing by rain, it is none the less true that in reality men are not thus care-taking. They squeeze from the land what they can get, and they are quite right in doing so, provided they do not press too hard. They seek always the largest money return from the land, and when, through increase of population, the time comes for getting profit by treating land more generously, it happens that what are commonly called improved methods of husbandry will be slowly established. The reason, by the way, why the more recent methods are called "improved" is, that fit alterations and adaptations of old methods to meet changed circumstances and new requirements are never generally adopted into a district so rapidly as they might be. There is always need of much debate, as well as criticism and condemnation of the older processes. Usually, many years must pass by before a prevailing system of husbandry

can anywhere be changed; and, for that matter, perhaps, there is no place in the world where the system in vogue is everything it should be. It has been well said, that men may be improving old methods perpetually, and yet the amount of good in the world remain much the same.

Practically the earlier methods of farming do tend slowly to depreciate the soil. It is only when methods are adopted which are based upon green fallows and stock keeping, or on irrigation, or the use of artificial fertilizers, that the fertility of land is fully kept up. This point is well illustrated by a letter from Jefferson to Washington, written in 1794. "I find," he says, "that a ten years' abandonment of my lands to the ravages of overseers has brought on them a degree of degradation far beyond what I had expected. As this obliges me to adopt a milder course of cropping, so I find that they have enabled me to do it by having opened a great deal of land during my absence. I have therefore determined on a division of my farms into six fields, to be put under this rotation: 1st year, wheat; 2d, Indian corn, potatoes, and peas; 3d, rye or wheat, according to circumstances; 4th and 5th, clover, where the fields will bring it, and buckwheat dressings where they will not; 6th, folding and buckwheat dressing. But it will take me from 3 to 6 years to get this plan under way. The maxim, 'Slow and sure,' is not less a good one in agriculture than in politics."

Landlords strive to sustain their Land.

The tenure of land, that is to say, the manner in which land is held, has often had an enormous influence upon the maintenance of fertility. A certain tendency to "run out" farms, which is noticeable in this country, while in Europe the rule is to "keep them up," doubtless depends in great measure upon the different tenures in the two countries. Wherever there are landlords and tenants, the former will look out more or less carefully for the permanent interests of the soil, but in this country, where the farmers commonly own the land they cultivate, there has practically been no one to represent the landlord's interest, for the attachment to localities is so slight, and land so abundant, that not many of our people have cared to consider whether their land was treated with absolute justice.

"In British agriculture," as Sir James Caird has put it, "there are two capitals employed, that of the landowner and that of the

farmer. The first, which is the land itself and the permanent improvements upon it, has hitherto been certain and safe, and therefore yielding a small return; the other, the live stock and crops subject to risk of seasons, and speculative, and liable to competition prices, requiring a much larger percentage of profit to cover risk. The capitalist is content with 3 % for his heretofore secure investment, which carried with it also influence and social position. A farm worth $250 an acre needs a further $50 an acre to provide the farmer's capital for its cultivation. The landowner is satisfied with a return of 3 % on his $250, while the tenant looks for 10 % for management and risk and capital on his $50."

"Suppose that a farmer has a capital sufficient to buy 100 acres at this price and stock them; he would get for his $25,000 invested in land $750, and for his $5,000 invested in farm capital, $500, together $1,250. But if he followed the custom of this country (England), and used the whole of his capital in cultivating another man's land, he would with his $30,000 hire 600 acres, on which his return ought to be $3,000. He in truth then trades on the capital of the landowner, practically lent to him at the moderate rate of 3 %, which he converts into a trade profit on his own capital of 10 %. The British landlord is thus the nominal owner of five-sixths of the joint capital embarked in agriculture, and upon him in the end the chief weight of any disaster must fall."

Fixed Rotations a Symptom of Conservative Farming.

In countries not given over to the commercial activity of modern times, in all easy-going countries, such as the England of a century ago, or the Germany of forty years since, there is a strong tendency for systems of husbandry, as well as everything else, to crystallize out into definite and seemingly permanent forms, depending upon the conditions and circumstances which obtain in the different districts. This fact is very well illustrated by the various systems of farming which were followed in England at the close of the last century, at the time when Marshall and Young travelled through that country and published their observations. It is manifest that at that time each special district had settled down into some one definite style of farming, which, while it kept the land from running out, and so satisfied the landlords, did at the same time afford profit to the farmer.

In many of the interior districts of England there were definite

systems of rotation, varying as to their details with the soils and the climate, and according as they were based solely upon the dung of neat stock or of sheep, or upon the use of lime or marl in addition to the dungs. But in the vicinity of London there was even then, as has been said under the head of Rotation, no definite rotation of crops, and the system of farming was dependent upon manure obtained from the city, — and it had been so dependent time out of mind. Thus Marshall, writing in 1799, says: —

"The course of practice in the Vale of London may be said to be altogether without regularity. What marks the practice of this part of the kingdom is, that the same lands, though in a state of enclosure and equally adapted to grain and herbage, have been continued, perhaps for ages, either under a course of arable management or in a state of perennial herbage, and have not been changed from grass to grain and grain to herbage, conformably with the practice of most other enclosed districts."

"Improper as this plan of management would be in ordinary situations, where the land has nothing but its produce to depend upon for its support; it would be, under due limitation, perfectly right in the neighborhood of the metropolis, or of other large towns, where the herbage of old grass-lands, whether for hay or pasturage, is required, and where a supply of manure can be had to keep up the arable lands in sufficient condition without permitting them to renew their strength occasionally in a state of herbage."

In like manner there was not at that time any definite system of rotations in the more backward districts of England, where pasturage was the prominent business. Thus, when Marshall studied the agriculture of Yorkshire, in 1782–83 and 1787, he could not find there any regular course of crops. Sheep and cattle were pastured through the summer, and there was grass-land enough to provide hay for their winter support; but, as is the case to-day in most parts of New England, none of the grass-land was broken up until it had become unproductive.

Examples of Old English Farming.

Under the head of Rotation the system of husbandry practised in Norfolk County has already been described. It was grain, turnips, grain, clover, — the turnips and clover going to support fatting cattle, whose dung served to produce grain, by keeping up the fertility of the land. In the Midland Counties of England

a somewhat different system was employed. The soil there is a deep sandy loam, and the farms were devoted to grain, dairying, and cattle-breeding. The rotation was one from grass to grain, as has been mentioned. In fact, the system had some slight points of resemblance with that which now prevails in New England, except that most of the grass-land was pastured, only a comparatively small amount of hay being there needed in order to keep stock through the mild winters. The plan was, greensward for 6 or 7 years, followed by oats, wheat, and barley, then grass again. It may be regarded as the old Yorkshire, or the present New England practice, systematized and reduced to line and rule, though perhaps not very wisely, on account of the repeated grain-crops.

The prevailing character of the soil in any given district, and its climate, naturally had a determinative influence upon the kinds of crops which were grown there. Thus, there were old English rules to the effect that calcareous soils produce good quality of barley, root and leguminous crops; while sandy soils are adapted for rye, flax, and roots of all descriptions. Stiff clays were held to be peculiarly adapted for the growth of wheat and of horse-beans, but they were thought to be not so well adapted as lighter soils for root-crops.

It was customary, formerly, in some parts of England to maintain second-rate store cattle upon barley-straw and a few turnips during the winter, to turn them out to grass in the summer, and either to sell them to the butcher in autumn or to fatten them further in early winter upon turnips and oil-cake. But in recent years it has usually been found more profitable to set about fattening the animals at once, i. e. during the first winter, upon turnips or mangolds and oil-cake. In this case, only the best of the straw is picked out by the cattle, and most of it is trodden into their manure.

All Forage should be put to Use.

It is important not to lose sight of the conception that, wherever possible, a farm should be conducted in such manner that everything produced upon it may be turned to profit. This idea seems self-evident, but it is by no means always acted upon. In some parts of Ohio, for example, and the adjacent States, it commonly happens, even now, in the grain-growing regions, that very much more coarse forage is produced than there is any use found for.

The farm animals are wintered on corn-stalks and straw, together with a little clover-hay and grain, though most of the hay is fed to working horses in the autumn and spring. But no pretence is made of using more than a small part of the straw, not even for bedding or for manure, and in addition to the straw there are large quantities of clover-stalks; for the second growth of clover is cut for seed, and the stalks are allowed to go to waste unfed and unused.

It would seem to the uninitiated that some system of turning these matters either into beef, or mutton, or wool, or merchantable dairy products, might be devised. Possibly, ensilaged cow-peas, or a similar crop, or perhaps even ensilaged corn-stalks plus cotton-seed-meal, or shorts, might serve as complementary food to balance the straws. But the main point to be insisted upon is that the farms, i. e. the crops, appear to stand in need of being rearranged so that they shall all pull together, as it were. In the words of Professor Miles, "Every interest of the farm has its influence, for good or ill, on every other interest, and the aim should be to make each supplement the others and thus aid in increasing the aggregate of profits. In a large proportion of cases, the net proceeds of the farm will depend more upon the harmonious adjustment of many details than on the disproportionate development of any special interest."

New England Farms.

The farms of New England may be classed roughly, and speaking in general terms, either as milk-farms or as sheep-farms. A few cattle are still reared, though the old system of stock-farms has practically been given up, because of the importation of cheap cattle from Texas and the West. Excepting those of choice breeds, the cattle now reared in New England come for the most part from wild bush-farms of the crudest description.

The best New England farms are devoted usually to the production of milk, to be sold as such, or to be converted into butter, or more rarely into cheese. Large quantities of hay, oats and potatoes are sold as such, and in the vicinity of cities various garden crops are grown. There are exceptional districts given over to onions, or cranberries, or tobacco, and other special crops. In some places, considerable rye is grown; in others, beans and peas. Sometimes small fields of wheat appear, and almost everywhere more or less maize.

Upon some of the milk-farms small quantities of roots of one kind or another are grown, and many farmers find profit in ensilaging fodder-corn. But beyond these things the agricultural products of New England are meagre, and upon the whole the agriculture is backward and uninteresting, excepting special regions, such as the river intervales and the districts manured with seaweeds. With the exception of the cases last mentioned, it is seldom that there can be found what may be called well-balanced farms, where palpable advantage is taken of some natural resource, or where the round of operations is manifestly judicious.

Farms based on Water-meadows.

As has been said, it is a common thing in Europe to see farms based upon permanent irrigated mowing-fields. Cattle are fed upon the grass, or winter-fed upon the hay, from these fields fertilized by water, and the dung of the cattle goes to manure the rest of the farm, which may thus be made to produce grain or potatoes, or some other crop for sale. This practice is a very old one, — so old, indeed, that everybody is supposed to know of it as a matter of course; hence less is said and written about it nowadays than would be well. It is interesting to observe that this method has come down directly from the time of common fields, and that it is perhaps the most conspicuous agricultural inheritance from that period.

It will be remembered that, in order to get manure for their grain-fields, the village communities often maintained permanent meadows, and wintered their cattle on the hay from these meadows together with the straw of their grain-crops. In many instances, the success of the grain-fields, i. e. the prosperity of the village, depended practically on the size and quality of the meadow; and just so in after years many a European farm has prospered or deteriorated according as the water-meadows attached to it were or were not large enough for its full support. Manifestly, if only its water-meadow be large enough, a farm may be carried on indefinitely, without need of buying in artificial fertilizers, or cattle food, or of hesitating to grow and sell exhaustive crops. Naturally enough, however, the tendency has been so to arrange farms that their meadows alone are not fully capable of supporting them. That is to say, it has been found more profitable, on the whole, to keep under the plough for the production of merchantable crops a part of the land which might well be meadow, and to aid in main-

taining the land in good heart by means of fallow-crops, rotations, oil-cake, artificial fertilizers, etc. It is evident, however, that even a small strip of water-meadow may be made to do much for the support of a farm, by using its products judiciously in connection with other forage-crops. Such meadows have the very great merit of certainty; and they are of special value in droughty years, when only light crops can be obtained from upland fields.

Marshes and Bog-meadows.

In New England, the intervale farms do in some measure belong to the class of water-meadows. So, too, do the salt-marshes of the seaboard, for they afford hay naturally without need of manuring. These marshes were very important adjuncts to the farms of our forefathers, and they played no small part in helping the early settlers to maintain themselves on this continent. We may even go one step lower, and include the rough sedge-hay of fresh-water-meadows; for there are numerous farms in New England that depend in good part upon such bog-meadow hay for wintering their stock. I have urged in the Bussey Bulletin, from chemical considerations, the importance of this hay, and it is evident from common observation that it has considerable value when properly used.

Indeed, it may be said of American farmers, that they have in general distinguished themselves chiefly by taking advantage of things lying at the surface. They have picked up many things that were lying in plain sight, but have seldom searched out and made full use of less conspicuous treasures. Ever since the country was settled, New Englanders have been cutting the natural swamp-sedges, and have even had the face to call the product "meadow-hay"; but they have not exerted themselves to establish water-meadows. It is true that at one time, long ago, there was a tolerably emphatic movement toward the embanking of salt marshes here in Massachusetts, and several tracts of lowland may still be seen at Hingham and Cohasset upon which excellent crops of English hay were formerly grown, year after year, without thought of manure. But most of the embankments were broken down by storms at the middle of this century, and the improvements wholly destroyed.

By means of a dike built in 1872–73, a considerable tract of marsh-land at Marshfield, in this State, was reclaimed from the sea and converted into valuable mowing-fields, though the proprietors

were much worried and disheartened by malicious depredations and lawsuits, as has doubtless often occurred in the history of such enclosures in other parts of the world. Miss Martineau wrote an interesting child's book, "Settlers at Home," based on the misfortunes of colonists upon the embanked marshes of the east coast of England. In 1896 an act was passed by the Massachusetts Legislature which may, perhaps, ultimately do away with the Marshfield dike.

When marsh-land has once been embanked, and means have been provided for removing the water that drains out from it, some little time is required even in regions where rains are abundant in order that the land may be freed so completely from salt and sulphides that all kinds of crops may be grown upon it. To facilitate the sweetening process, ditches are dug to receive the water that leaches from the soil, and care is taken not to plough the land very deeply at first. By growing grass and clover as soon as the land will carry these crops, the soil will the sooner become fit for supporting other kinds of plants. Or, best of all, whenever practicable, as on a small patch of marsh lying at the base of a hill, and in places where the marsh-land is divided into compartments by cross dikes, the saline soil may be flooded with fresh water, after the draining-ditches have been dug, and kept under water for several months, in order actually to dissolve out a good part of the hurtful matters. In any event, it is important to have the main lines of the ditches so arranged that there shall be no difficulty in providing for the drainage of any depressions which may be formed on the surface of the soil, at places where the spongy peat has settled upon itself more emphatically than it has done elsewhere, for if water finds opportunity to stand on such sunken spots the soil there will soon become unfit for the growth of useful plants.

Importance of Pastures in New Countries.

The merit of good natural pasture is of course specially conspicuous in sparsely-settled countries, and in the absence of forage-crops. Thus, Thorold Rogers, in explaining the early agricultural wealth of Oxfordshire, dwells upon the facts that this county possesses a large amount of natural pasture, and that, down to the time when winter-roots and artificial grasses were generally cultivated, pasture bore a very high relative rent. In the Middle Ages this rent was between 8 and 12 to one compared

with arable. He urges that there is no reason to believe that the hay-crops produced in the wild stretches of pasture on the Upper Thames and other streams of Northwestern Oxfordshire were less 500 years ago than they are now, and he vouches for it that the demand for pasture was far more urgent than it is in recent times.

One Advantage of Wild Pastures.

Even at the present day, it is noticeable that very many New England farms are supported in some part, much as the common fields of the village communities were, by wild grasses obtained from bog-meadows, salt-marshes, and pastures. There are comparatively few farmers among us who do not support certain parts of their estates by means of manure which has been derived from other parts. They take the surplus strength of the wilder lands and bring it to bear upon the cultivated fields. It is practically a mere matter of taking fertilizers from one place and bringing them to another; and it is to be noted that the system now in question is closely related to the common plan of feeding animals with the refuse of crops, such as straw, corn-stover, and beet-cake, as a means of getting manure to grow grain. So, too, when bran, brewers' grains, Indian corn, and oil-cake are bought for feeding animals, fertilizers are brought from other men's farms to our own.

Where the chalk-downs of England, which consist of a thin soil reposing on rock or rubble of chalk or limestone, adjoin better land, the system has sometimes been adopted of keeping large flocks of sheep on the down, and folding them on the arable land. In this way, it was often found to be possible — even before artificial fertilizers were obtainable — to carry out a four-course rotation on land naturally fitted only for courses of five or six fields, and to add at least a third to the amount of wheat produced, and sometimes even to double it. Where folding was thus practised, on farms consisting of one-third down-land, it was estimated that 8 or 9 more bushels of wheat to the acre were obtained than could have been got from similar soil without the sheep.

The Milk-Farms of Saxony.

A good example of a highly artificial arrangement is seen in the Saxon milk-farms. Potatoes are grown freely in that country, and upon this crop farms are often based, as follows: A

stable of milch cows, whose milk is sold as such, or made into butter or cheese. Potatoes, as the chief crop, to be fermented and distilled to whiskey upon the farm, where the residue from the distillation (slop), together with straw, is fed to the cows through the autumn and winter. During the spring and summer the cows are fed upon mown clover and other green forage. Large quantities of dung are produced in this way in the course of the year, — enough to serve, not only for manuring the potato-fields, but to give great crops of wheat, and rye, and rape-seed, all of which are sold off the farm, as well as the whiskey and the milk products.

Working upon this basis, the Saxon farmer is contented with a very small margin of profit, or even with no profit at all, from the milk and the products from milk. He keeps the cows primarily in order that they may manufacture manure out of the potato-slop. Or, to look at the matter from another point of view, potatoes are grown in order to get manure for the grain. Practically, when such an establishment is working well, the farmer does get three profits, — one from grain, one from whiskey, and one from milk, — and he has, moreover, three strings to his bow. If the times are such that wheat yields no profit, money may still be got from the whiskey, and so conversely.

These milk-farms flourished particularly near the middle of this century, before methods of transporting animals upon railways had become systematized, at a time when bread was still regarded as the staff of life, and when Germany was so poor a country that comparatively little flesh was eaten there, and hardly any market at all for well-fattened beef could be found upon the Continent. At the very time when multitudes of farms in England and Scotland were based upon the production of meat, no profit could be got in Saxony by stall-feeding neat cattle, and the farmers were forced to keep cows, as has been said, not as a direct source of income, but as a means of obtaining dung for the production of grain and other merchantable products.

Products which Remove no Fertilizers.

The foregoing example manifestly presents a definite, well-considered plan for a farm; i. e. a plan based on rational thinking. Just so, upon almost any European farm we can see tolerably clearly the principles on which the system of culture depends. The farmers strive also to produce such things as sugar from beet-

roots; oil from rape-seed or linseed; spirit, or starch, or glucose, from potatoes and grain; and butter from grass; — all of which products are non-nitrogenous and free from ashes. That is to say, the farmer's aim is to produce things which (when sold) shall not carry off fertilizing matters, and which shall leave residues, like press-cake, oil-cake, and slop, that are highly nutritious, and yield rich dung. It was a fruitful precept of the old German agriculturist Block that, "in order to the permanent fertility of a farm, its products should all be derived from the air." To which dictum Walz added the proviso . . . "or from the yearly disintegration of [mineral matters in] the soil [or from matters brought to the land in water]." While to-day we may safely make the further addition . . . "or from matters brought to the farm in the form of cattle-food or of commercial fertilizers."

Arrangements such as the foregoing were devised long ago, before the days of artificial fertilizers, when the great desideratum was that the farm should support itself without need of buying manure. But it is usually hard to detect any good and sufficient reasons for the methods pursued upon many of the farms of New England. There are doubtless some farms, based upon the use of peat-composts, which are eminently philosophical, and which probably represent the best results thus far obtained in this region; and a similar remark will apply, perhaps, to some small dairy-farms where cattle are soiled, and to those milk-farms where rough fodder is reinforced with cotton-seed-meal, or the like, and to some farms also where ensilage is used. But it cannot be said of either of these systems that they have become general, nor is it true that the use of peat compost has been reduced to a definite rule of practice.

Large Farms versus Small Farms.

It is difficult to discuss the subject of farms without making some allusion to the question of large farms versus small farms, which has greatly exercised the minds of statesmen and political economists in Europe. The question is really, What are the respective merits of farms dependent upon capital and worked as factories, and of farms occupied and worked by peasants or yeomen as mere homes? There is a great deal to be said upon both sides of the question.

There is something very attractive in the idea of a farm handled as a mere manufacturing establishment, in which, by labor-

ing upon the raw materials, soil and manure, we elaborate, with the aid of various natural forces, the desired crops. By operating in this large way, i. e. upon what is called the manufacturing scale, it is possible to apply scientific knowledge more directly than is usually practicable upon small farms, and to make use of the best implements and devices, such as draining and irrigation, for example. It is notorious, withal, that every improvement thus far made in European agriculture has been developed by the large-way farmers, the peasants having simply followed where the larger proprietors led. All this, not of fundamental necessity perhaps, but because of the real weakness, narrow-mindedness, and sluggishness of the small farmers. But, on the other hand, the picture of the peasant proprietor supporting himself and his family in absolute independence upon a small patch of land has many pleasing features.

In favor of the large farms, it is argued that experience has shown that capital may be applied to farming, as well as to other employments, provided only there be room enough for it to act. It would be absurd, of course, to employ a skilful steward or overseer, at a large salary, unless there was a sufficient amount of land to occupy him fully, or, rather, to the best advantage. The analogy of other kinds of business teaches that, up to a certain point, there is an advantage in operating in the large way. Large farmers are generally rich farmers, i. e. they have command of capital; and, other things being equal, the rich farmer will be more likely to cultivate the land carefully and understandingly, and to put it to good profit, than the poor one. Throwing gardens out of the account, it is commonly observed that large farmers have better crops, as the general rule, than small farmers.

Arthur Young long ago collected statistics upon this point. He found that the crops of the large farmers were in fact very much better than those of the small. One of the results of his inquiry shows, however, as might have been expected, that there is a limit beyond which increase of size ceases to be an advantage. Thus, while he found that English farms of from 200 to 400 acres were in his day better for live stock than smaller ones, in the average proportion of 5.5 to 3.5, they were more than five times better than the still larger farms that came under his observation.

Young's inquiry was directed to the comparison of the ordinary run of English farms of his time; he did not, in this particular in-

stance, take into account the small peasant farms that are now so common in Europe. But it is to the consideration of these last that the discussions among politicians have been mainly devoted.

In countries where the peasants are habitually industrious and painstaking, their little farms have an enormous advantage over large farms in respect to the cost and the quality of labor. Farm labor, in order to be applied to the best advantage, should be executed not only with judgment, but with interest and devotion. The peasant takes the field with his wife and children, and not only utilizes much labor that would have no merchantable value, but he has always an eye to the judicious and constant application of the labor. The cost of the labor applied to his land is consequently low, while the effect produced by it is great. Herein the peasant is specially favorably circumstanced as compared with the large-way farmer, whose hired laborers have comparatively little interest in their work, and who cannot be subjected to anything like the oversight that is constantly present, as a matter of course, upon the peasant farm. It is from this cause more particularly that, in regions where peasant proprietors abound, the produce of the large farm suffers severely in the markets from the competition of the peasant's crops. This statement is particularly true of backward countries like France, where there is no great demand for labor in the occupations other than farming. Wherever machines can be used with advantage, i. e. in countries where labor is scarce and in demand, and land cheap, the peasant's hand-grown crops would be dearer than those of large farms.

What is a "large" Farm?

There has been, at one time and another, a certain amount of discussion as to what should be understood by the terms "large," "medium," and "small farms." Some writers have classified farms from the number of ploughs. For these writers, "three ploughs" means a large farm, and "two ploughs" a medium-sized farm, while a farm using no plough at all would be small. Other writers have classified farms by the number of acres. For them anything over 300 acres would be called large, while farms containing from 100 to 300 acres would be medium.

Other observers have maintained that neither of these definitions is sufficiently precise. They have suggested that a large farm is one that cannot be directed by a single man, and a me-

dium farm one that can be directed by one man, though that man will have no time at all to work himself; while every farm carried on by the members of a family should be called small. This last definition is probably the best. At all events, it justly disposes of the average New England farm by relegating it to the same class with the farms of peasant proprietors.

As a general rule, to which there are of course some exceptions, it may be said that, as farms pass from those which may be classed as gardens to those which are really large, less and less human labor needs to be employed for the cultivation of them.

Farming without Live Stock.

One desideratum at the present time, in certain localities, is to be able to farm profitably without keeping much live stock. Upon really good land, competent to produce valuable products, the artificial fertilizers permit the farmer to carry out this idea, provided the farm and the crops are so arranged that little or nothing shall be produced which is not directly salable. In general, it is the production of rough or refuse forage, and the existence of rocky or hilly pastures and low-lying marshes or meadows, which necessitate the keeping of cattle, much more than any need of their dung. If corn-stalks and bog-meadow hay, or clover even, are harvested, cattle must be kept to eat them lest they go to utter waste.

Still, a certain amount of farmyard-manure is a very useful basis of operations, particularly as a means of moistening and ameliorating certain soils and for growing some kinds of crops, and the problem really is how to supplement with artificial fertilizers the least amount of dung that can be used profitably, rather than how to get along without any dung.

Since farmyard-manure, regarded as a source of plant-food, is not by any means perfect, but stands in need of being supplemented with one or another kind of special fertilizer, according to the several classes of crops that are to be grown, it will manifestly be philosophical, whenever the comparative price of fertilizers and dung will permit, to apply the dung in quantities smaller than those indicated by tradition, and to reinforce it with such additions of the special fertilizers as may be needed. It is precisely because of the want of just proportion in farmyard-manure that the purchase of small quantities of bone-meal to be applied to turnips, of Stassfurt salts for cabbages, or of nitrate

of soda for wheat, may in many situations be better and more economical farming than the buying of fodder wherewith to maintain a larger herd or to make better dung. To each and to every farmer the question is continually presented anew, How many, or rather how few, cattle shall be kept, in order to the best advantage of myself and my land?

The Question of selling Hay.

To the mind of the average New Englander, the selling of hay from any farm which is not situated upon bottom land or near a city, or within reach of abundant supplies of sea-manure, is a wellnigh criminal offence; for, as is well known, the hay-crop carries off from the land large quantities of fertilizing matters. Lawes and Gilbert have shown that 2,700 lb. of hay obtained from one acre of an old unmanured mowing-field contained 159 lb. of mineral matter, or about one and a half times as much as was carried off by their unmanured crops of wheat and barley. On manuring the grass-field with ammonium salts alone, 224 lb. of ashes were taken away annually from the land in the hay-crop, or from one and a third to one and a half times as much as was removed by wheat or barley similarly manured with ammonium salts. When mixtures of ammonium salts and ash-ingredients were applied to the grass, some 4 cwt. of ashes to the acre were carried off by the hay. On manuring with farmyard-manure, 307 lb. of ashes were taken away, and 374 lb. were taken on dressing the field with a mixture of farmyard-manure and ammonium salts. As for nitrogen, 40 lb. of it were taken off from the acre, in the unmanured hay-crop, and as much as 115 lb. when the land was forced with heavy dressings of ammonium salts and ash-ingredients.

But from the modern, and particularly from the chemical point of view, the selling of hay is a most commendable practice, provided only that the hay brings a proper price, and that the farmer uses some part of the money thus gained to replace fertilizing matters which the hay-crop has taken from the land. For many parts of New England at the present time the chief crop to be aimed at is merchantable hay. Only it needs to be obtained at small cost. Ordinarily such hay is got either from bottom lands or from moist slopes manured naturally by the ground-water; or it is grown by means of dung obtained from animals that have been fed in some part on bog-meadow hay, or other unmerchantable

product reinforced with shorts, or corn-meal, or cotton-seed-meal. There are many farms where the fertilizing influence of clover on the growth of hay proper is felt to a certain extent, though hay which contains much clover is seldom sought for, or esteemed among us as a salable crop.

The proper ways of getting hay in this region, without cattle, would seem to be artificial irrigation, and composts reinforced with additions of phosphatic slag, floats, Stassfurt potash-salts, or wood-ashes. It would appear that only materials of low cost can be used, and that nitrogen should be got by composting in some way the soil of the farm. There are probably few situations in New England where it would be remunerative to use costly fertilizers for producing hay alone. Unless some salable interpolated crop can be got by artificial fertilizers, the latter should either be let alone upon a hay-farm, or used with very great caution. It is well understood in this vicinity, that, as things are now, it is quite out of the question to get a profit from hay by means of the ordinary run of commercial fertilizers, applied directly to the grass. Even in the days when high farming was profitable in England, Lawes and Gilbert urged that, as a rule, "Artificial manures can only be used with advantage and economy for the hay-crop when the land receives periodically a dressing of farmyard-manure." For reclaimed bog-meadows Fleischer recommends top-dressings of kainit to be applied early in autumn at the rate of 500 or 600 lb. to the English acre, either by itself or in conjunction with powdered phosphate-slag used at the rate of 350 lb. to the acre at first, and with gradual reduction in subsequent years even to as little as 175 lb.

In the vicinity of Boston the hay-farmer suffers from the competition of hay grown upon bottom lands of rivers, which are in some instances hundreds of miles distant from the market; i. e. he has to compete with hay that has been grown by natural irrigation at little or no cost for manure. Much hay is brought to the city also from wild, cheap upland soils in regions less liable to drought than Massachusetts is.

An interesting method of keeping up hay-farms in the region about Boston consists in taking pleasure-horses to board during the winter months; that is to say, instead of hauling hay into the city for sale and hauling out manure to spread upon the grass-fields, the plan is to take in horses enough to consume the hay at

the farm, and to apply their dung to the land. The price of board is such that the hay is sold at a higher rate than could be got for it as hay, while the fertility of the farm is maintained.

CHAPTER XXXV.

GENERALITIES AS TO THE GROWTH OF CROPS.

THE reasons which go to determine the cultivation of any one kind of plant in a given locality, or upon a given farm, as well as those which cause other kinds to be neglected, could be best considered under the separate heads of each special crop. But there are certain general conceptions, relating to the growth of plants, which may well be treated of together.

Movements of Matters in the Plant.

Thus, the passage of the various constituents of a plant from one part of it to another, as the plant advances to maturity, is a capital fact common to all plants, though perhaps different as to degree and method in each and every different kind. When a seed germinates, many of the matters in the seed pass from it into the roots and sprout in order to form these organs. So too, after the act of germination has been completed, and the plant devotes its energies, first to the development of roots, and then to the development of leaves, the same rule holds good, and the workings of it are particularly conspicuous after these organs of assimilation have been perfected, and the forces of the plant are seen to be devoted more especially to the formation of flowers and fruit and seeds, or to the production of fleshy roots, or of buds for next year's use. When a leaf is growing vigorously, much of the nutrient matter, which is produced in it, is consumed for the growth of the leaf itself, but at the time when the leaf has ceased to grow, and has not yet begun to wither, the same active production of nutrient matter continues for the benefit of flowers, fruits, seeds, etc., which can only be developed after many leaves have formed upon the plant.

In one sense, the prime purpose of the plant is to produce seeds which shall carry forward the life of the plant into another generation. In this point of view, the seed is a condensed and concentrated plant — wellnigh free from any unnecessary or extraneous matter — which holds within itself the essence of the species. As

is well known, the seed is made up of the so-called embryo or miniature plant, and a surrounding store of alimentary matter, consisting of starch, oil, albuminoids, etc., which shall serve to feed the embryo at the time of germination; the seed contains also those ash-ingredients — notably phosphates and potash compounds — which are absolutely essential for the seedling's life. But to perfect these all-important seeds the energies of the plant are devoted from first to last, and to this end the several organs of the plant are developed, each in its turn.

In autumn, the more valuable contents of the mature leaves of trees pass back into the tree itself, and contribute to the equipment of the buds from which the new leaves of the coming year are to start; while the dead leaf that falls is a mere skeleton, as it were, of woody fibre, which contains comparatively little either of nutritive or of fertilizing matters. It is true not only of trees, but of most plants, that during the final ripening period, as indeed through each of the successive stages of growth which have preceded it, matters pass freely from one part of the plant to another, for building up and nourishing the various organs. Naturally enough, these movements are more conspicuous at some stages of development than at others. The function of leaves, for example, is primarily the elaboration of crude inorganic materials taken from the air and the soil; and during the larger part of the leaf's life it will be occupied in manufacturing food for the support of other parts of the plant. But after a time, when the leaf has grown old, and the purpose of its life has been accomplished, then even its constituent parts are free to be used for other purposes, and we see in fact that the oldest leaves gradually wither and die as they give up to the newer parts of the plant many of the matters that were contained in their cells.

This migration or translocation of the constituents of plants is true not only of the various inorganic or ash-ingredients, but of many of the organized matters as well. Several of the "proximate constituents" of the plant, notably albumen, sugar, starch, and oil, are moved about from one part of the plant to another, as occasion may require. It may well be true, indeed, that some of the ash-ingredients are translocated only by virtue of the fact that they form a constituent part of the organized matters.

Since the movements of the ash-ingredients admit of being rather more easily studied than those of the organized matters, it was

not unnatural that chemists should, at one time, have devoted particular attention to that branch of the subject, though it is now evident that the movements of the organized matters are really of most importance, practically speaking.

Translocation of Matters in Ripening Grain.

There are many familiar facts which enforce the practical importance of attending carefully to the study of these changes in position of the components of plants. It is known, for example, that the young shoots of rye, or oats, or wheat, or barley, are exceedingly nutritious fodder, and that they are greedily eaten by animals; but, on the other hand, the straw of these several plants, that of oats perhaps excepted, does not attract animals at all, unless they are very hungry, or unless they have been trained to eat straw, or unless, as the common saying is, they find opportunity to steal it. It is known, too, that in the life of every grain-crop there comes a time when the plants "stop growing" and "begin to ripen their seeds." In other words, there comes a time when the plant ceases to draw much food either from the air or from the soil, and devotes itself to the process of concentrating in the seed the nutriment which previously was scattered through all parts of the plant.

Pierre found, on studying the development of wheat-plants, that the amount of dry organic matter in the plant reached its highest point some 15 or 20 days before complete ripeness; after which time the amount of matter lost from the plants by oxidation (respiration) was larger, or at the least no less, than that gained by way of assimilation; but at this very time the matters in the plants continued to move freely out from the leaves and straw into and towards the seeds.

After-ripening of Grain.

Even when a plant is cut down while its seeds are soft and milky, there will still be the so-called "after-ripening," provided the seeds are allowed to ripen in connection with the stem, and to draw nourishment from it. A useful application of this knowledge may be had by pulling up tomato-vines, just before the advent of frosty nights, and hanging them in an unused greenhouse or warm glazed shed, so that the unripe fruit which remains attached to the vines may have an opportunity to ripen off gradually. It is to be noticed that, in the case of this tropical plant, warmth, as well as shelter, is needed for the after-ripening of the

fruit. These instances, like those previously cited, are mere consequences of the transference of various constituents of the plant from one part of the plant to another, and they illustrate very forcibly the arguments to be set forth.

When to Harvest Crops.

It is from a knowledge of the laws which control this transference of matter that just conclusions may be drawn as to the times of harvesting crops, and as to the manner of treating a crop according as it is intended to be used as grain or as forage. It may seem absurd, perhaps, to many persons, to insist that the discovery of a scientific principle like the one now in question, the knowledge of which dates but a few years back, has taught to farmers some highly important lessons as to the times and seasons at which crops may best be gathered. But it is unquestionably true that this discovery has given precision and definition to several matters which were previously not a little obscure.

The example well illustrates the difference between empirical and scientific knowledge. There must always have been numerous farmers who had learned from personal experience just when to gather grass or grain in order to the best results, and the example of these sagacious persons must have been followed more or less closely by their neighbors. But so long as the experts had no sufficient reason to offer for their practices other than that they knew their way was the best way, they were subject to criticism and animadversion, and their methods could hardly ever be universally accepted. In point of fact, the times of harvesting did differ appreciably in different localities, and it was not until chemical analysis had taught the composition of the crops at the different stages of their growth that any one really knew just what was right and proper to do in the matter of gathering grain or grass.

The importance of knowing when to harvest a crop is seen most conspicuously in the improved methods of making hay which are now in vogue. There was a time, not very long ago, when much of the hay-crop in New England was left standing until it was mere straw; the argument being that grass "shrinks" excessively when cut before it is "ripe." On the other hand, at the time of my first visit to Germany, in 1855, I had opportunity to listen to Stoeckhardt's presentation to Saxon farmers of the to them novel idea that rowen hay is a valuable food for cows. They had pre-

viously entertained the notion that rowen must be wellnigh worthless as cattle-food because it is immature. They contrasted it with full-grown hay to its disadvantage, much as a laboring man would contrast veal with beef. But these men were among the very best farmers in Europe. I was the more impressed with this example, because familiar with the high estimation in which rowen was held at that time by New England farmers.

Researches as to the Times when Translocation occurs.

The investigation of the times and seasons when matters are transferred from one part of the plant to another has thrown considerable light on the theory of rotation also, and on the question of the exhaustion of land. It was thought formerly by many practical men that crops do not really exhaust the land, excepting at the moment when their seeds are forming, i. e. after the act of blossoming and during ripening. This idea was based in part on the palpable fact that, in a given weight of seeds, there are contained more nutritive matters than in any other part of the plant, whence it was not wholly unnatural to conclude that a great deal of nourishment had to be taken in by the plant during the formation of the seeds. But probably the chief reason for the belief was the familiar fact that several of the crops which are mown in blossom impoverish the soil much less than those that are left to ripen seeds. Clover and vetches, for example, had long been considered to be not only non-exhaustive, but decidedly ameliorating crops.

This opinion as to the exhaustive character of ripening crops was combated by the noted French agricultural writer Dombasle, who argued that the formation of seeds, and, indeed, all the work of organization that occurs in a plant after the time of flowering, depend solely on the store of matters which have been accumulated in the plant previous to that time. To him it seemed plain that the young plant accumulates food in such large quantities that, at the time of flowering, it has become a reservoir full of materials proper for the formation of the seeds.

He dwelt on those facts of practical experience which go to show that plants take as much food from the soil at the beginning of their development as they do when their growth is more advanced. Among crops reputed to be highly exhaustive, he cited several, such as cabbage, tobacco, and woad, which do not bear seeds; and he urged the well-known rapid loss of fertility in seed-

beds, where young beets and rape are started. He maintained that the reason why certain green crops are non-exhaustive depends upon the fact that they leave in the soil a great mass of roots, which is not only large as compared with the total weight of the crop, but also as compared with the residue left by other plants which have been allowed to draw "juices" from their roots while ripening their seeds.

In the year 1820, towards the end of June, Dombasle marked 40 wheat-plants which were in blossom, and took up 20 of them, while the other 20 were left to complete their growth. After having been dried, the first lot was found to consist of 43 grm. roots and 126 grm. stalks and leaves, or all together 169 grm. Two months later, when the crop was harvested, he collected the other 20 plants, and found that they contained 27 grm. roots, 86 grm. stalks, leaves and chaff, and 67 grm. grain, or together 180 grm. Whence it seemed to appear that in two months' time the twenty plants had gained no more than 11 grams, or about $\frac{1}{16}$ their total weight. In other words, his experiment seemed to show that the plants had accumulated, previous to the moment of flowering, $\frac{15}{16}$ of their final weight. It was evident withal, that, if the wheat had been mown when in blossom, an amount of matter equal to one-quarter the weight of the harvest would have been left in the earth in the form of roots, while the ripe plants would have left in the soil no more than one-seventh the weight of the sheaves.

Twenty-five years after Dombasle, Boussingault urged, as a fact of observation, that plants which have been pulled up out of the earth after flowering will still perfect seeds, if they are kept properly moistened, although they have no connection with the soil. He stated that he had himself seen oat-plants bear a small number of well-formed seeds when taken from the soil at the time of blossoming, and thereafter kept with their roots in distilled water. From all of which evidence, as he urges, there can be no doubt that the substances such as sugar, starch, and albuminoids, which have accumulated in the plant previously to the moment of the fecundation of the flowers, do gradually pass out from the roots and leaves and stems, towards the place where the fruit is to be developed. Meanwhile the green color of the leaves is seen to fade gradually, in consonance with the movements aforesaid.

A similar experiment with oat-plants was tried long afterwards by Heinrich, who took up some of the plants from a dry, sandy soil when they were in blossom, carefully washed off the adhering earth, and placed the roots in a jar of distilled water. The plants thus treated ripened sooner than those left standing in the field, though the seeds they bore were lighter than the field-grown grain; and it was in evidence that nearly three-quarters of all the matter necessary for the formation of the seeds had been taken into the plants by the time they came into flower. It is a fact of familiar observation withal, that really mature clover- or beet-plants, such as have borne seeds, can no longer be regarded as fodder, since they now consist almost entirely of residual, tasteless woody fibre.

But Boussingault did not hesitate to urge that the results of Dombasle's experiments must have been altogether exceptional, and that plants do continue, as a general rule, to assimilate matters from the air and the soil, even after the time of flowering. It is now known, in fact, as regards this matter, that much depends on the weather, and on the condition of the soil in which the plants are standing. When moisture and food come to a crop, even tolerably late in life, they may cause it to grow with considerable freedom.

If Dombasle's conclusion was strictly true, viz. that a crop mown in flower contains almost the whole of the organic matter which it is capable of accumulating, and that it then affords about as much nutritive matter as it would if left to ripen some two or three months later, the inference would logically be drawn that it might often be more advantageous to mow crops when they are green, and to use them as fodder, rather than to wait for the grain to ripen. For by proceeding in this way it would be possible to sow and mow two crops upon the land in a single year.

To test the matter, Boussingault chose wheat-plants from a field, as Dombasle had done, but he collected a much larger number (450) at each of the stages of growth, and he subjected them to analysis after they had been dried and weighed. The results of this interesting research are given in the following tables: —

450 plants collected on the 19th of May, 1844, yielded, —

Air-dried stalks and leaves	277 grams.
" roots	46 "
	323 "

On the 9th of June, when beginning to blossom, —

Air-dried ears in bloom	111	grams.
" stalks and leaves	850	"
" roots	100	"
	1,061	"

On the 15th of August, at the time of harvest, —

Air-dried grain	677	grams.
" chaff	155	"
" straw	928	"
" roots	121	"
	1,881	"

It appears from these figures that between the beginning of blossoming and complete ripeness, the plants had nearly doubled their weight (100 : 177), which is a very different result from that got by Dombasle.

The crop actually harvested from Boussingault's field was at the rate of 1,685 kilos of grain, and 2,681 kilos of straw and chaff, to the hectare; and there were 300 kilos of roots, according to the best estimate that could be made; — in all, 4,666 kilos.

From the analyses of the selected samples, and analysis of the seeds sown, the following table was calculated. It shows the weight in kilos of matters obtained from the crop grown upon a hectare (2.5 acres) of land: —

Dates at which the Plants were collected.	Dry Plants.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
19 May	689	257	40	354	12	26
9 June	2,631	1,008	163	1,371	24	66
15 August (harvest)	4,666	1,736	317	2,324	42	187
Increase from 19 May to 9 June,	1,942	751	123	1,017	12	40
Increase from 9 June to 15 Aug.	2,035	728	154	953	18	121

Thus it appears that, while 751 kilos of carbon were assimilated between the 19th of May and the 9th of June, before the time of flowering, there were 728 kilos of carbon assimilated between the 9th of June and the 15th of August, between flowering and ripeness. 12 and 18 kilos of nitrogen respectively were assimilated in the two periods. If it be assumed that the wheat grew continually from the 1st of March to the 15th of August, the rates of increase may be stated as in the following table: —

Times of Growth.	No. of Days of Growth.	Kilos gained per Day and Hectare. Dry Organic Matter.	Carbon.	Nitrogen.	Ash.
1 March to 19 May	79	6.82	2.75	0.12	0.26
19 May to 9 June	21	92.95	35.75	0.54	1.92
9 June to 15 August	66	30.84	11.03	0.28	1.82
Mean assimilation per day and hectare		28.95	10.88	0.25	1.18

It is now known that, during the first period of growth, plants devote themselves particularly to the production of roots, hence the comparatively small amount of matter produced above ground at that time in this experiment; but during the second period, while the wheat-stalks are shooting up, there is a large gain of carbonaceous organic matter (cellulose, etc.). Boussingault concluded, from his results, justly enough, that while there could be no doubt that assimilation was very rapid in the younger plants which he examined, or that it gradually diminished as the plants approached maturity, it was none the less true that the plants did produce, i. e. assimilate or take in from the air and soil, a great deal of matter after the time of flowering.

In other words, it may be said once more, that the plant is occupied at first with the work of developing roots, then with the growth of the vegetative organs, then with the formation of flowers, and finally with the perfecting of fruit, or, in the case of biennial plants, with the storing up of a reservoir of provisions, as in roots and tubers for next year's use; and that at each of these several stages most of the work done relates to the chief purpose of the period, though the lines of demarcation between the periods are seldom clearly defined, and some work proper to the earlier periods is still done during the later stages of development.

It should be said that Boussingault collected materials for a similar study of a leguminous crop, viz. beans; but the increase of vegetable matter produced in this case after the time of flowering was so very large that he deemed it wholly unnecessary to resort to analysis to put the fact in evidence.

Influence of Climate on Translocation.

The ripening of a plant, like its growth, will in any event be largely influenced by the weather to which the plant happens to be subjected, and by the abundance of the supply of food to which it has access. All kinds of plants go to seed soonest on poor, dry land, and on the driest parts of a field; while plants that are fed with active nitrogen compounds show very little inclination to form seeds, but only stems and leaves.

During the later stages of its life, the ripening of a plant may be hastened by a higher temperature, while during the earlier stages of development an access of heat might simply cause the plant to grow faster than it was growing before. When wheat or turnips are sown on rich soils in England in June, the plants will

run to leaf, and exhibit little inclination to form seeds, but when sown on poor land, even early in the spring, they will run rapidly to seed, unless the land is heavily manured. Drought and cold often tend to accelerate the seeding process. The cold nights of late summer and early autumn have no little influence in checking growth and hastening ripening.

When a soil or a climate hastens ripening, it diminishes the weight of a crop. What is gained in time is in great measure lost in bulk. Earliness and productiveness rarely go together, unless, indeed, liberal manuring is resorted to, for manure may often act in some sort as an equivalent for time. (Russell.) It has been noticed, in respect to wheat, that its productive powers seem to be largest in climates which are cool and moist during the growing season. Under these conditions, the plant expands more fully than it does elsewhere. The tendency to form flowers being retarded, stems and ears are formed upon a large scale, and a corresponding yield of grain follows in due course.

The foregoing statements refer, of course, to climates suitable for wheat-growing. The development of the plant would naturally be abnormal in regions not adapted to it. Thus, according to Gasparin, wheat never ripens in some droughty countries where the temperature of the air does not fall below 68° during the entire year. In such places, the soil becomes dry before the stalks of the wheat-plant have had opportunity to shoot up, while the temperature of the air rises to 72 or 74°, and the wheat remains in its leafy stage of development, i. e. as mere grass or sod. Humboldt noticed that the wheat sown on the mountain-slopes at Jalapa, in Mexico, grew vigorously enough at first, but never sent up any spikes. It was cultivated there solely for the sake of its leaves, which served as a succulent fodder for animals. As Gasparin has urged, this fact illustrates the truth that the act of blossoming is not an essential phase in the development of some agricultural crops. Not only may wheat thus be grown in some localities as a grass-crop, but peas also, when sown on heavily manured land, may be made to produce vines merely, i. e. stalks and leaves, without any flowers.

Translocation during Germination.

An excellent illustration of the kinds of changes which occur when matters are translocated in plants is seen when a germinating seed throws out its roots and sprout. If there was oil in

the seed, it changes to soluble mobile sugar, which moves to places where it is needed, and is there changed to new substances; to cellulose, for example, for building the sprout, or, at a later stage, it may even change back to oil, if need be. It has been noticed, in fact, during the ripening of oily seeds, that the increase of oil is coincident with a diminution of sugar. Starch changes to sugar also, and albuminoids change to amids or to peptones, as will be explained directly.

So, also, when a plant begins to grow independently of the seed, and to obtain food from the air and the soil, organic matters, such as sugar and amids, are sent down from the leaves into the roots for their nourishment, while ash-ingredients, water, and nitrogen compounds pass up from the roots for the support of the entire plant. In general, soluble amids that come from albuminoids, and soluble sugar that comes from starch or oil, are specially prominent, considered as materials for the formation of new cells and new contents of cells. In all such changes, however, portions of the original matters in the seed are lost through processes of oxidation and evolution of carbonic acid, so that the weight of the new roots and sprout is considerably less than the weight of the seed, — sometimes as much as one-half less.

Migration of Special Substances.

With regard to the translocation of individual substances, it has been proved that albumen, and the allied matters called albuminoids, are moved from the leaves of grain-plants through the stem into the ear, where they accumulate in large quantity; and that starch also is moved about freely from the leaves and stalks to the seeds. Sugar is known to move about freely, and it is probable that gum also is moved in a similar way, and perhaps cellulose even, to a certain extent.

The movements of albuminoids are specially interesting, both because of the great importance of these substances, and because of the apparent difficulty of translocating them. They are "colloid" bodies, such as can pass only very slowly and with great difficulty through membranes like those which form the walls of plant-cells. But it has been perfectly well made out that, as a preliminary to their moving from one part of the plant to another, the albuminoids are changed to the condition of amids, such as asparagin, leucin, tyrosin, glutamin, or the like. These amids are crystalloid bodies, and, unlike the colloid albumen, they can

pass readily by osmose through the cell-walls, and so reach the places where albuminoids are needed. There they are changed back to the albuminoid condition.

These changes have been well studied in the germination of certain seeds. When the seeds are exposed to warmth and moisture, chemical reactions set in; and among these reactions is one whereby some of the albuminoids of the seed are changed to asparagin (or the like), which is easily soluble and diffusible, and so passes readily into the young sprout of the plant. Both asparagin and leucin have been found, for example, in young pea and vetch plants that had just started from seeds. Boussingault noticed, long ago, that amids are abundant in the shoots of germinating plants, in etiolated plants, and in those parts of plants from which light has been purposely excluded. Meanwhile the darkened plant ceased to grow or to increase in weight. All of which goes to show that, in these cases, amids are formed either by the splitting up or the oxidation of albuminoids. But when light is admitted to a plant which has become charged with amids by being kept in darkness, the amids speedily disappear, and the plant proceeds to grow naturally, and to increase in weight.

Asparagin was first discovered, at the beginning of this century, in asparagus sprouts, having been derived in this instance from the roots or root-stalks, instead of directly from a seed. It is now known that, beside a great stock of albuminoids, considerable quantities of amids are always stored up towards autumn, as a reserve of nitrogenous food, in root-stalks and tubers, such as those of the potato, and in root-crops as well. Next year, when the roots are planted for the sake of getting seeds, the amids serve at once to nourish the young sprouts and rootlets. It is evident enough that the amids have a highly important part to play in the physiology of vegetation. They occur abundantly in those parts of plants where growth is most active, and are changed to albuminoids after their translocation.

Some plants contain ferments, analogous to pepsin, or trypsin, which are capable of changing albuminoids to soluble peptones. A striking example of the significance of the peptones is seen in the case of insectiverous plants. But beside peptones, which diffuse rather slowly, there are formed by the splitting up of albuminoids in seeds and roots, a variety of other substances,

such as leucin and tyrosin, which move from one part of the plant to another with comparative ease.

Ordinarily, however, there is produced in the process of germination much more asparagin than there is of leucin or the like, and it is now recognized that this abundant formation of asparagin is due to the actual oxidation of a part of the albuminoid matter in the seed. (Loew.) In illustration of this fact, Palladin found that he could immediately put a stop to the free formation of asparagin, in sprouts that were a week old, by placing them in an atmosphere free from oxygen, although the sprouts thus situated continued to live for a day, and although leucin continued to be formed in them — by the action of a ferment analagous to trypsin — not only while the sprouts were living, but even after their death. In some cases there is formed, instead of asparagin, the next higher homologue to it, viz. glutamin.

Probably there are other ways, also, in which some part of the albuminoids may move about in the plant. Schumacher has noticed, indeed, that when albumen is mixed with a solution of phosphate of potash, its rate of diffusion through membranes is considerably increased. There is good reason to believe that such a mixture might pass from one part of a plant to another much faster than albumen could pass by itself. And, as Pfeiffer has suggested, it is possible that an albuminoid insoluble in water, such as legumin, for example, might be dissolved by phosphate of potash, and in this state pass through the walls of cells until the place destined to receive legumin was reached, and there the legumin might be deposited in mass simply by the withdrawal of the solvent phosphate.

Simultaneous Movement of Phosphates and Albuminoids.

Inasmuch as it is well known that phosphoric acid passes out of the stalks and leaves of plants into their seeds, and accumulates in the seeds just as the albuminous substances do, it is a not unnatural inference that the movements of the two substances may be interdependent, or in some way connected. Indeed, the idea that some sort of connection exists between the movements of phosphoric acid and albuminous matters is a tolerably old one. It had been talked about long before the publication of Schumacher's observation.

One point that was adduced as evidence in support of the idea

is the fact that in fruits and bulbs which contain much starch and but little albuminous matter there is but little phosphoric acid; while, as was just now intimated, those plants and parts of plants which are richest in albuminoids, likewise contain the largest proportion of phosphoric acid. The potato, for example, well illustrates this point. It contains on the average about 2 % of albuminoids, and less than 0.2 % of phosphoric acid, while horse-beans, with their 25 or 26 % of albuminoids, show nearly 2 % of phosphoric acid.

From observations such as these it was argued, many years ago, that the amount of nitrogen assimilated by a plant probably stands in some very simple proportion to the amount of phosphoric acid taken in by the plant, and has an intimate physiological connection with this phosphoric acid. Several instances were recorded in which this proposition seemed to hold good, particularly in respect to the seeds of the plants that were examined. Thus Mayer found in oats and wheat and barley the relation 1 P_2O_5 to 2 N, very nearly; while in rye it was 1 : 2.2, in peas 1 : 3.7, and in beans 1 : 3.4. Fittbogen contrasted light and heavy barley as to this point. He divided a quantity of the grain into 7 different parts of as many different specific gravities, and found that the proportion of P_2O_5 to N varied between 1 : 1.82 and 1 : 2.43, though with no great regularity. In ripe barley grown to perfection in pots of sand, he found the proportion to be 1 : 1.66; and in the unripe grain it was 1 : 1.72.

This idea of fixed proportions has often been disputed, notably by Siegert, who has declared that P_2O_5 and N do not bear any constant relation to each other, either in wheat or rye. He found, too, that nitrogenous fertilizers increase the percentage of nitrogen in these grains, and diminish the percentage of phosphoric acid. The discussion has been not a little clarified by the remark of Loew, that inasmuch as phosphoric acid is an essential constituent of the albuminous nuclein which is indispensable to the nucleus of each plant-cell, it follows as a matter of necessity that phosphoric acid and albuminoids must move together.

It is probable, nevertheless, that albuminoids may be transferred from one part of a plant to another in several different ways. Sometimes they may move as such, or with the help of phosphates, or they may pass to and fro by being changed to diffusible amids that are subsequently reconverted to albuminoids.

Solution by Digestion.

It is true, moreover, that albuminoids, and starch also, may be changed to mobile substances within the plant by processes of digestion and fermentation analogous to those which occur in the bodies of animals. The study of insectivorous plants has shown that such plants secrete acid juices, which digest and dissolve the edible portions of the insects, and in many plants unorganized ferments have been detected, which are capable, when in presence of acids, of changing albuminoids to soluble, diffusible peptones. Some of these ferments can change starch to sugar also.

It is generally felt, nowadays, that much more knowledge must be acquired in respect to the kinds and amounts of the several different albuminous matters in plants before anything definite can be said or believed as to the relations which subsist between phosphoric acid and these substances, either in general or in respect to any particular one of them.

It may be added that Arendt, in the course of his elaborate study of the growth of oat-plants, found that although the rates at which phosphoric acid and nitrogen were assimilated were not constant throughout the entire life of the plants examined by him, there was nevertheless a decided tendency towards the proportion 1 phosphoric acid to 4 nitrogen, which was the one found in the ripe plants. In oat-seeds, the proportion found by Arendt was 1 : 3. But his plants are known to have been exceptionally rich in nitrogen, and his results support in this respect the statement of Siegert, above mentioned.

Arendt found, nevertheless, that phosphoric acid passed continually, and in large quantities, into and towards those organs in which albuminoids were forming or to be formed, in spite of the fact that, when once formed, the albuminoids are quite independent of phosphoric acid for their continued existence, or at all events need only a very minute quantity of it.

Wetzke has tabulated as follows the results obtained by Heiden, Voigt, Güntz, and himself, as to the proportion of nitrogen to phosphoric acid in seeds, according as the crops were manured with one or another kind of fertilizer. For each part of phosphoric acid in the seeds there were found the following parts of nitrogen: —

	Oats. 1869.	Oats. 1870.	Oats. 1871.	Rye. 1873.	Rye. 1875.	Rye. 1877.	Vetches. 1872.	Peas. 1876.
In the seed sown . . .	2.53	2.45	1.70	2.13	2.01	2.18	4.86	4.94
No manure	....	....	....	1.56	1.83	2.09	5.76	6.07
No manure	1.78	1.76	1.82	1.67	1.96	2.29	6.75	5.28
Lime	2.31	2.94	1.52	1.44	1.90	2.11	6.56	4.00
Sulphate of ammonia .	2.50	1.20	1.83	1.70	1.80	2.67	6.35	4.01
Phosphate of lime . .	2.83	1.68	1.67	1.46	1.74	2.29	4.67	5.55
Sulphate of lime . . .	2.17	1.62	1.16	1.80	1.93	2.21	6.73	6.05

Although there are wide variations, it appears that the nitrogenous fertilizers tend to produce grains rich in nitrogen in the case of the cereals, while they do not in regard to leguminous plants. With the legumes, the phosphatic fertilizers seemed to diminish the proportion of nitrogen in the seeds.

Movements of Phosphoric Acid.

The movements of phosphoric acid from one part of the plant to another are very remarkable. Indeed, this substance is the most mobile among all the inorganic constituents of the plant. The facility with which it moves about is very much greater than that of the nitrogenized matters. As regards the oat-plant, Arendt found phosphoric acid passing continually from the lower parts of the plant into the upper parts, especially after the time of flowering. The upper leaves and the stem gave up at least five-sixths of all the phosphoric acid they had accumulated, and sent it into the ears. A very large part of the phosphoric acid in ripe grain has thus been moved from the leaves and the stem, after having once come to rest, as it were, in those organs. One thousand oat-plants contained in their several parts, at the stated seasons, the following amounts of phosphoric acid, in grams: —

	3 lower Leaves open, 2 upper Leaves closed.	Not yet fully headed.	Just after Blossom.	Beginning of Ripening.	When Ripe.
3 lower joints of stem .	0.47	0.20	0.21	0.20	0.19
2 middle joints of stem .	. . .	0.39	1.14	0.46	0.18
Upper joint	. . .	0.66	1.73	0.31	0.39
3 lower leaves	1.05	0.70	0.69	0.51	0.35
2 upper leaves	1.75	1.67	1.18	0.74	0.59
Ear	. . .	2.36	5.36	10.67	12.52

Functions of Phosphoric Acid.

It has long been known in field practice that phosphates play an important part in the development of young plants at the moment of germination and immediately after germination; and chemists have observed, in harmony with this fact, that there is present in the protoplasm of the vegetable cell, and especially in the nucleus of each cell, an albuminoid substance called nuclein,

which contains several per cent of phosphorus, taken, of course, either from phosphates in the original seed or from phosphates in the soil. Chlorophyl also contains phosphoric acid as an essential constituent. It follows, of course, from these facts, that phosphoric acid is required for the building of each and every plant-cell, and that it is important, not only for the young plant, but at all stages of the plant's progress. Loew has shown, by experiments upon algæ, that chlorophyl does not form in the absence of phosphates; but on adding phosphates to the suffering plant, he observed that cell-division took place at once, and that the plant became dark green, and developed chlorophyl in abundance.

One difficulty which would naturally be met with on trying to grow crops with an inadequate supply of phosphoric acid is illustrated by the following observation of Lawes and Gilbert. Barley was grown for 29 years in succession on two plots of land, both equally well supplied every year with assimilable nitrogen, but to one of the plots there was applied also a mixture of salts of potash, soda and magnesia, while the other got these things and superphosphate of lime in addition. It was noticed of the crops grown on the land which got none of the phosphate, that they did not assimilate carbon so readily as those grown on the other plot, although the color of the plants which got no phosphatic manure had always a darker green shade than that of the plants which were completely fertilized. At any period of growth, the dry substance of the crops which got none of the phosphatic manure undoubtedly contained a higher percentage of nitrogen than the others, and yet, in the absence of the phosphate, the assimilation of carbon was so deficient that 500 lb. less of carbon were harvested per year and per acre over the whole period of 28 years.

In a similar sense, experiments by A. Mayer have shown that a rapid production of albuminoids may be obtained on applying to rye- and grass-plants even a comparatively small proportion of an assimilable phosphate, together with an abundance of nitrate of soda, while in case there is a deficiency of phosphate in the soil, nitrate of soda has but little effect to increase the quantity of albuminoids in the plants.

Phosphates and Nitrogen form Plasma.

In explanation of the results obtained in his pot-experiments, where sugar-beets were supplied with varying quantities of plant-food, Hellriegel urges that, when a plant begins to grow, there is

formed in it, first of all, a quantity of plasma, which is a definite chemical compound, rich in nitrogen. By the help of this plasma, or rather, as it might almost be said, from and through the plasma, the young plant is enabled to assimilate food, and to produce new stores of starch and sugar, and other organic substances. In a soil wholly devoid of phosphoric acid, he noticed that the beet-plants starved, even from the time of germination, while beet-plants which had received no nitrogen, or only very small quantities of nitrogen, proceeded to form as much plasma, and as many cells, leaves, etc., as could be made from the scanty supply of material, and then waited, so to say, for reinforcements. In other words, the plants inadequately supplied with nitrogen did not die immediately; the plasma within them remained alive for a long time. Although such plants were small and stunted, they continued to perform the functions proper to a normal plant, excepting that they did not grow freely. The final result in such cases was a small plant, normally developed in all its parts, but extremely poor in nitrogen, while the percentage proportion of dry matter, and of sugar in it, was for that very reason high.

When his plants were supplied with less nitrogen than was required for the best results, it was observed that the weight of the total crop diminished, together with the number of leaves produced, but that the weight of the leaves remained proportional to the weight of the roots, while the quantity of dry matter in the roots and of sugar also increased. On the other hand, when the beet-plants were supplied with food in which there was an abundance or an excess of nitrogen, plasma formed in them freely, and in some instances in quantities larger than were useful, so that the normal conditions of vegetation were interfered with, and some of the plasma continued to live on until very late in the season. There resulted in this case large, leafy plants which, although they yielded a heavy burden of crop per acre, were nevertheless watery, and rich in nitrogenous matters and in substances that had not yet been changed to sugar.

When insufficient quantities of potash were given to beet-plants which were amply supplied with nitrogen and phosphates, an abundance of plasma formed in them, but the conditions were not favorable for the production of starch — as will be explained in a subsequent paragraph. Most of the starch which did form was used up again for making the walls of new cells, and there was

comparatively little of it left to be changed to sugar, so that both leaves and roots were poor in sugar. It appeared that, although there were about as many leaves on these plants as on those which got the normal quantity of potash, the weight of the leaves was less than that of the leaves on normal plants. Moreover, while the weight of the total crop diminished somewhat as the supply of potash was reduced, this diminution fell more particularly on the roots than on the leaves. The weight of dry matter in the crop, and of sugar also, diminished when the supply of potash was inadequate.

By supplying food in proper quantities — and his experiments showed that, in order that a beet-plant should grow really well in a jar containing 29 kilo. of quartz sand, it was necessary that there should have been added to the sand 2.9 grm. of nitrate-nitrogen, 1.2 grm. of soluble phosphoric acid, and 1.7 grm. of potash, beside adequate quantities of lime and magnesia and of a sulphate — Hellriegel found that he could obtain a maximum crop of beets and a maximum production of sugar, but that the amount of crop, of leaves, of sugar, and even of nitrogen, potash and phosphoric acid in the crop, could be changed at will by incorporating with the sand in which the plants were grown more or less of one or another of the different kinds of plant-food.

Lecithins.

In addition to the ordinary fats and oils, such as occur in plants, often in very large quantity in many kinds of oily seeds, there are certain phosphorized fatty substances known collectively under the name of lecithin, which is supposed to be a normal, essential constituent of plants, and of animals also. Lecithin, or rather, the lecithins, are wax-like substances which dissolve, together with the ordinary non-phosphated oils, when vegetable matters are extracted with ether. Ordinary lecithin is distearic lecithin ($C_{44}H_{90}NPO_9$) and is composed of glyceryl united to two stearic-acid radicals, to phosphoric acid, and to cholin ($C_5H_{15}NO_2$). This lecithin can readily be decomposed into glycero-phosphoric acid, cholin and stearic acid. But there are other lecithins that contain, instead of the stearic radical, the radicals of other fatty acids, and which yield these acids on being decomposed. For example, there is an oleic lecithin and a palmitic lecithin also.

Some chemists have thought that chlorophyl may perhaps be a kind of lecithin in which the radical of an acid, known as chloro-

phyllanic acid, plays a similar part to that of the fatty acid radicals in ordinary lecithins; for when chlorophyl is treated with a boiling alcoholic solution of potash, there are obtained glycerophosphoric acid, cholin, and chlorophyllanic acid, as products of the decomposition.

The Acid Juices of Plants.

The development of vegetable acids within the plant, and the changes they undergo, are subjects of no little interest, which would naturally come up for discussion in considering the ripening of fleshy fruits. It is probable that many of the changes of coloring observed in flowers, in ripening fruits and berries, and in autumnal leaves, may depend intimately on an increase or a diminution of acidity. Many fruits change color while they are ripening from green to red or violet. Sometimes the green passes through yellow, red, and violet, even to blue. But as a general rule green unripe fruits are palpably sour, and the acidity is seen to diminish as the fruit ripens and changes color.

The color of some kinds of flowers passes from red through violet to blue, as the flowers grow old, and that of the leaves of many kinds of trees in the autumn changes from green, through orange and yellowish red, to reddish brown or red, much in the same way that, in the laboratory, most yellow vegetable coloring-matters undergo change when they are subjected to the action of alkalies. (Schuebler.) It is a familiar observation, moreover, that a good part of the tartaric, malic, oxalic, and other acids in leaves and in unripe fruits, may change to sugar as the fruits become ripe. So long as the acids themselves exist in the plant, they are held in combination, i.e. usually and for the most part, as acid salts, by potash, soda, lime, or magnesia, while the sugar into which the acids are finally converted has apparently no need of the presence of potash or any other base. It has been thought, indeed, that when grapes ripen the proportion of potash contained in them diminishes. It follows necessarily, that, for the case now in question, potash, or some other base, is, up to a late stage of growth, really essential as a preliminary, so to say, to the formation of sugar from the acids at the time of ripening.

Movements of Starch.

It is known that starch, as well as the albuminoids, is moved from the leaves into the fruit, where it often accumulates in large quantities; that it is first organized in the leaves, and that it

passes thence into and towards the fruit, being made soluble in some way within the cells, and dissolved to such an extent that it can pass little by little through the cell-walls by way of osmose, and again change to true starch on occasion. The fact already insisted on, that starch forms freely by virtue of cell-action, even in the dark in green leaves which have been deprived of starch and then immersed in a solution of sugar, goes to show how readily starch may be deposited in any part of a plant in which sugar has been formed, or to which sugar may be carried.

Highly interesting experiments relating to the formation and translocation of starch have been made by trying to grow plants — well fed in other respects — in soils which contained no potash. Under these conditions, plants do not thrive, and very little starch forms in their leaves. It is to be inferred withal that the utility of potash, as regards starch, does not depend upon its alkalinity, for none of the other alkalies are competent to take its place. In the absence of potash, crops will not grow, and starch will neither form in them nor move in them, no matter how much soda, lithia, cæsia, or rubidia may be offered to them, but there is an interesting observation of Naegeli's to the effect that certain fungi can perfectly well bear the presence of compounds of rubidium and cæsium, and that these elements can even serve as food for the fungi and take the place of potassium.

In order that starch may move in ordinary plants, some lime is needed as well as potash, and so is a minute proportion of chlorine. The action of chlorine in aiding the movement of starch has sometimes been spoken of as akin to that of iron in developing the green grains of chlorophyl, in that an extremely minute amount of it is competent to do much work. In the absence of iron, the leaves of plants are apt to be white and not green. By means of the microscope, observers have seen the chlorophyl grains begin to grow and continue to prosper as soon as they gave a little iron to plants that had previously been deprived of that element.

As for chlorine itself, it is not disposed to accumulate in one part of a plant more than in another; nor does silica move about with any freedom; on the contrary, it remains wherever it may once have become fixed. Lime, also, seems to be tolerably equally distributed in all parts of the plant. According to Aschoff, it is not probable that chlorine has any particular function to perform in the plant, though it appears that a small quantity of it must be present in each and every cell in order that the cell may develop.

The oily matters in plants seem to be products of the transformation of starch (or of some of its isomers). It is noticed, for example, that seeds which are highly charged with oil when ripe contain starch while they are immature, and that the proportion of starch diminishes during the process of ripening, while that of oil increases. Conversely, it has long been known that the oil in oily seeds changes back to starch or sugar when the seed germinates.

Movements of Potash.

As was just now said, potassium must be present in the plant-leaf in order that the act of assimilating carbon from the air shall be accomplished. By operating on aquatic plants (algæ) by way of water-culture, it has been found to be practicable to check the process of assimilation — particularly in respect to the formation of starch — by placing the plants in a solution which contains nitrate of lime, sulphate of magnesia and monophosphate of soda. Under these conditions, any store of starch which the plants may have contained at the beginning of the experiment quickly disappears — for so long as the starch lasted it was put to use for building new cells — and the plant is left starch-free and in a fit condition for the trying of experiments on the ways and means by which starch is produced in the plant. (Bokorny.)

So too, Assfahl, in his experiments on feeding plants with glycerin, noticed that the presence of a compound of potassium seemed to favor the process by which glycerin was changed to starch within the plant. In consonance with the foregoing statements, Lawes and Gilbert — in their experiments on the manuring of grass-fields — found that potash serves a highly important purpose in promoting healthy growth. On those plots to which potash salts were applied, together with other fertilizers, "there was a very marked tendency to form stems and seeds, while without the potash there was much less of this character, the herbage being more leafy and less dense, and having much less inclination to mature."

On dressing a field of true grasses with an active nitrogenous fertilizer, together with potash salts, the crop formed stems and seeds and matured readily and normally, while in case there was any deficiency of potash the character of the herbage deteriorated, the amount of grass produced diminished, and the practical efficiency of the nitrogenous manure was lessened. Meanwhile it

was noticed that almost identically the same amount of nitrogen might be taken up by the herbage growing with a deficiency of potash as by that abundantly supplied with it; and that the color of the vegetation where there was not enough potash was a very much darker green than that fully supplied with potash. And yet, taking the average of the 8 years succeeding the first 6 of the exclusion of potash from the fertilizers, there was nearly 400 lb. less carbon assimilated by the grass per year and per acre, and in some of the still later years, the deficiency was much greater than this. Hence it appeared that when potash was deficient, nitrogen was taken up as freely as ever, and that chlorophyl, of a sort, was produced in abundance, but that the production of carbonaceous matters by the plant was impaired unless a due supply of potash was present. On grass-land carrying a fairly mixed herbage, moderate dressings of active nitrogenous fertilizers together with a liberal supply of potash salts increased the growth of leguminous plants, and that of the grasses also, while a deficiency of potash greatly diminished the growth of leguminous plants, and was unfavorable for that of the true grasses.

The fact that plants will neither grow normally nor ripen properly in the absence of potash, may readily be shown by growing buckwheat in pots of sand, with which a little bone-ash has been mixed, and watering them with a highly dilute solution (1 : 1000) of nitrate of lime. The green color and the leafiness of the plants will show that they are getting all the nitrogen they need, while their crippled condition and the tendency to remain young point emphatically to the need of potash.

Generally speaking, potash appears to be rather evenly distributed throughout the plant; but it has been noticed that it seems to pass slowly out of grain into the straw at the time when the grain is ripening. At all events, this backward movement is true of the oat-plant, in which Arendt found more potash in the stem than elsewhere. The maximum of potash was in the lower part of the ripe stem, and above this point the proportion of it diminished as the plants were older.

Both Arendt and Bretschneider have observed that no more potash is fixed by oats after the grain has begun to ripen. According to Arendt, the maximum of potash in the ears was at the time of blossoming; after that time, the proportion of potash in the grain diminished, while the proportion of magnesia increased. The move-

ments of potash in wheat-plants has been studied in no little detail by the French chemist Pierre. (Hoffmann's Jahresbericht, 1875–76, p. 304.)

It is interesting to note that, in studying the growth of the potato — a starch-producing crop — Lawes and Gilbert observed that, on their land, mineral manures alone, i. e. a mixture of phosphatic and potassic fertilizers, had more effect than nitrogenous manures alone, but that, when mineral constituents were adequately supplied, the further addition of nitrogenous fertilizers was essential for the production of anything like full crops. They found that while the purely nitrogenous manures had little influence to increase the production of solid matter, the mineral manures alone increased it by nearly 1,000 lb. per acre, and the nitrogenous and mineral manures together increased it by about 2,600 lb.

Curiously enough, the purely nitrogenous manures did not enable the tubers to take up an appreciably increased amount of potash, while in the cases where mineral and nitrogenous manures were applied together, large quantities of potash were taken up; indeed, nearly one-half of the 150 lb. of potash annually supplied was recovered in the increased produce. Even by the use of superphosphate of lime alone, 30 lb. more potash were taken up per acre than was contained in the crop from unmanured land; and it was remarkable that only 3 lb. more potash were taken up under the influence of a mixture of mineral fertilizers which contained, beside superphosphate, etc., 150 lb. of potash.

Movements of Magnesia and Lime.

Magnesia passes from the lower stem to the upper parts of the plant, and increases constantly in the grain. Arendt found that the dry matter of the ripe ears of 1,000 of his oat-plants contained almost 3 grm. of magnesia and 2.5 grm. of lime, and many other analysts before him had found that there is more magnesia than lime in the ashes of oat-grain; but while magnesia continued to move into the ears of Arendt's plants until they were ripe, the lime in the ears reached its maximum before ripeness, and thereafter passed out of the grain, as it were, while magnesia was still passing in. He found also that the leaves were much richer in lime than in magnesia. Some of the proportions were as follows: 16 : 3; 16 : 2; 17 : 2. And, in general, there were 5 or 6 times as much lime as magnesia in the leaves. But in the

stem the relation between the two bases was usually 1 : 1, or 1½, and on only one occasion did he find twice as much lime as magnesia. All these items of information mean something, of course, although no one has yet discovered what their meaning is.

As has been said in volume I, it is true of all kinds of crops that lime is found in abundance in their leaves, at all stages of growth, and it is known that the presence of lime is essential for the proper development of leaves. According to Von Raumer, lime plays an important part in those reactions occurring in leaves, by means of which cellular tissue is built up. By its help the cell-walls thicken and solidify, and it may be said of it that compounds of lime are needed for the conversion of starch into cellulose, though they seem to have very little influence either on the formation or the moving of starch.

Schimper has argued that lime serves one useful purpose, by combining, with the oxalic acid which is often formed in plants, to render it insoluble and harmless. Loew, also, has observed that very dilute solutions of oxalic acid, as well as solutions of soluble oxalates, even those which are neutral, are extremely poisonous to the higher orders of plants, and to algæ also, though not poisonous to fungi which contain no chlorophyl.

Loew argues that a compound of calcium — apparently a compound of calcium and nuclein — is an essential constituent of chlorophyl grains, and of the nuclei of cells, and that this calcium compound is readily removed, and the cell thereby destroyed, when oxalic acid is permitted to come in contact with it. One function of lime is to prevent this injurious action of the oxalic acid which is formed in plants, by combining with it, as fast as it may be produced, to form insoluble calcium oxalate. In view of this fact, the well-known tendency of lime to accumulate in leaves is seen to be due to the circumstance that it happens to be put to use there. It has been observed, withal, that leaves suffering from albinism contain but little lime.

It is to be understood, however, that lime is chiefly important in that it forms part and parcel of the chlorophyl grains. The fact that it may serve, on occasion, to neutralize oxalic acid, must be regarded as of secondary importance, the more especially since there are some kinds of plants which do not generate this acid. In harmony with the foregoing statement, it has been noticed repeatedly that lime is not needed by certain fungi which have no

leaves. Ordinary beer-yeast, for example, has been grown with success in the entire absence of lime. (A. Mayer, and Cohn.) The experiments of Loew also go to show that beer-yeast contains no organ of which lime forms an essential part.

Magnesia, on the contrary, is said to be important for the development of beer-yeasts, and has been thought to be as necessary as phosphoric acid is for the growth of such fungi, though Loew has remarked that the power of moulds to grow in strongly acid nutritive solutions which contain no magnesia may perhaps be explained on the ground that, under such conditions, the moulds can assimilate phosphoric acid from calcium phosphate, which would be made soluble by the acidity of the liquor. Von Raumer has maintained that magnesia, as well as lime, is in some way intimately connected with the formation of chlorophyl. In the absence of magnesia, chlorophyl ceases to form. Magnesia helps to move starch also, especially the starch from which chlorophyl is to be formed.

According to Loew, magnesia is specially important in vegetable physiology because it is a weak base, the salts of which are easily dissociated. The phosphoric acid, for example, so necessary for the formation of the nuclei of the cells of plants of the higher orders, can probably be taken from phosphate of magnesia more readily than from any other phosphate. Biphosphate of magnesia is more soluble, also, than the corresponding lime phosphate, and can move about within the plant more readily. Hence a probability that the special function of magnesium salts is to keep up a supply of the biphosphate for the formation of nuclein and plastin wherewith to build up new cells and chlorophyl grains, and thereby the plant itself. Lecithin and casein also may get their phosphorus from this source. In harmony with this idea are the old facts of observation that magnesia is found in largest proportion in those parts of plants, notably the seeds, where phosphoric acid is found, and that magnesia, as well as phosphoric acid, follows the same course as the albuminoids in its migrations within the plant.

Functions of Sulphur.

Sulphur, which is taken into the plant in the form of sulphate of lime, sulphate of magnesia, sulphate of potash, or some other sulphate, goes to form an integral part of the albuminous matters in the plant, and of course moves about with these albuminoids

towards the uppermost part of the plant, and towards the grain and fruit. Many plants contain also sulphuretted essential oils of peculiar and characteristic odor and taste. This statement applies to the onion and to garlic, horseradish, mustard, cress and many others.

Where Ash-Ingredients do their Work.

It may be said in general of the ash-ingredients, that their work is at the extremities of the plant. It is in the leaves and young stems, and in unripe seeds and fruit, that the largest proportions of useful ash-ingredients are found under the ordinary conditions of growth, when the soil in which the plant is standing contains no excess of soluble inorganic matters. In old wood, on the contrary, the proportion of ashes is proportionately small.

It appears, therefore, that in the economy of nature a very small proportion of inorganic materials is sufficient to perform the physiological functions necessary for the growth of plants; and this fact has indeed been fully proved by experiments on the growth of plants in water and in sand.

Accidental Ash-Ingredients.

It is a matter of observation that most plants can, on occasion, take in far larger quantities of ash-ingredients than they have any use for. Thus, certain oat-plants grown by Wolff by way of water-culture yielded ashes which contained 38% of lime, although usually the ashes of the oat contain rather less than 4% of this constituent. Indeed, it has been noticed that plants have sometimes carried without injury more than ten times the quantity of potash, soda, chlorine, or the like, that would be sufficient for their perfect development. It is true enough that different species of plants differ not a little in respect to their power of supporting a great excess of ash-ingredients. The plants, such as saltwort, that grow upon saline and alkaline soils, can take up without harm a far larger quantity of common salt than can be taken up by wheat. But there is always a limit to a plant's power of supporting the presence of an excess of inorganic matter; and the health of a plant may easily be disturbed by some kinds of ash-ingredients as soon as any undue quantity of them has been taken up.

Is Silica of any Use to Plants?

The foregoing remark may perhaps need to be qualified in so far as it applies to silica; for the amount of this substance that can be

supported by some kinds of plants is little short of appalling. There is no suggestion either of limit or of regularity as to the amount that such plants may take in. Ashes have sometimes been found to contain more than 70% of silica, while in other instances only traces of this substance could be detected. There are numerous plants which appear to have no real use for the large quantities of silica which are commonly found in them. Maize, for example, has repeatedly been grown in the absence of it. Indeed, Jodin has grown, by way of water-culture, four successive generations of maize-plants, which got no silica other than that from dust in the air, or from the substance of the vessels which held the solutions in which the plants grew. The silica was, in fact, reduced to an extremely minute trace, without any injury to the normal development of the plants. As a result of numerous experiments of similar tenor, a feeling has become somewhat general that it is hardly possible that silica can have any direct or conspicuous part to play either in the formation or the moving of organic matters. But, on the other hand, the large amounts of it found in the stalks of grain and grass, — to say nothing of the scouring-rush (Equisetum), — continually suggest a doubt whether such plants may not in some way derive advantage from it.

Ritthausen has suggested that silica may possibly do good by clogging in due season the cell-walls of the older parts of plants. He urges that, when silica is deposited as a gelatinous or flocculent mass on the walls of cells, the diffusion of the sap must there be hindered, and very much in the same proportion as the amount of the silica, so that finally the movement of sap will cease in the leaves specially affected. But this gradual dying of the lower leaves is helpful for the growth of new leaves and shoots in other parts of the plant, to which the useful matters that were contained in the lower leaves will naturally flow while the latter are dying. In this point of view slow clogging is essential; for if the lower leaves were to perish suddenly, their constituents could not pass out from them, and would consequently be unable to serve any useful purpose for the rest of the plant. The deposition of too much silica in the earlier stages of growth would be harmful, by causing premature destruction of the leaves before they had fulfilled their legitimate purposes, so that the normal development of the plant would be impaired.

Experiments made by Wolff by way of water-culture, and con-

tinued through several years, go to show that silica helps the formation of grain. In the case of oats, at least, a larger number of perfect grains were formed in the presence of silica than in its absence. Other experiments by Wolff seemed to show that when silica is present, a smaller amount of phosphoric acid may be sufficient for the proper development of oat-plants than is required when silica is absent. It was found, moreover, on growing oats in solutions from which all "unnecessary" ash-ingredients had been excluded, that the least possible amount of phosphoric acid by means of which the plants could be brought to perfection was always larger than the smallest amounts that have been observed in plants grown naturally in the fields, that had free access to silica, and which yielded ashes very rich in this constituent. Indeed, Wolff has shown that, as a general rule, the non-essential ash-ingredients seem to exert no little influence on the assimilation of the essential ingredients. Thus, on seeking to ascertain how small an amount of each kind of food may be taken in by oat-plants when an abundance of all other kinds of food is present, it was found that the plants needed to contain at the very least the amounts stated in the following table, in which the figures represent percents of the dry matter of the ripe plants: —

	Nitrogen.	Potash.	Lime.	Magnesia.	Sulphuric Acid.	Phosphoric Acid.
Least possible Amount	0.7	0.5	0.16	0.1	0.1	0.35
Amount needed for good medium development .	1.0	0.8	0.25	0.2	0.2	0.50

But in remarking upon the circumstance that the figures in the last line of the table correspond tolerably nearly with the average amounts of ash-ingredients which are found in ripe oat-plants that have grown in the fields, Wolff calls attention to the fact that, unless "non-essential" ash-ingredients were present, he was never able to grow a plant which contained at one and the same time the least quantities of all the essential ash-ingredients.

In point of fact, the amounts of ashes taken in by his plants were always much larger than the sum of the least possible quantities, as given in the table. Far from getting plants which yielded less than 2% of ashes, the least amount of ashes obtained by Wolff was 3%, and in actual field-practice so small an amount as 5% is seldom obtained. In order to check this excessive consumption of the essential inorganic matters, it was necessary

to supply the plants with one or another "non-essential" constituent, such as silica, or lime, or phosphoric acid. In other words, it was found that the oat-plants developed more completely when they had taken in a certain quantity of "non-essential" matter in addition to the strictly necessary minimum amounts of essential ash-ingredients. According to Wolff, it is only when in presence of an excess of other ash-ingredients that the 0.5% of phosphoric acid, or the 0.8% of potash, mentioned in the table, can do their perfect work.

Vigorous Plants take up much Mineral Matter.

Other things being equal, vigorous, succulent, luxuriant plants usually contain as large a proportion of ash-ingredients as those of scantier growth, and they often contain more than the latter. Experiments go to show that grain-plants usually contain more potash and lime, and less silica (often less phosphoric acid also), when they are rank and succulent, than when they are stunted, whence the inference that from one and the same soil more ashes will be taken up by a vigorous than by a feeble crop. Weeds are noticeably rich in ashes.

It may be said, in general, that from a soil highly charged with plant-food a crop will take up far more of some kinds of nourishment than it has any use for; but that this excess will not increase the yield of the crop, nor do the plant any good. As regards the grain-crops, the excess of ash-ingredients thus taken up over and above what is needed for moving the starch and albumen, or what not, is simply heaped up in the straw, and in this fact is found the reason of the high estimation in which straw is held as a manure. If hay is to be sold off a farm, it will be better to sell that mown upon old fields rather than that from newly-manured land, where the crop will naturally have surcharged itself with ash-ingredients.

Familiar Examples of Movements of Matter in Plants.

Beside the very evident changes which occur when plants are ripening their seeds, there are other familiar appearances which enforce the lesson that each part of a plant has its own particular purpose to perform for the support of the other parts. For example, the great general fact, that one set of organs may take the things necessary for them from another set, where they have been elaborated, is clearly illustrated when a cutting is planted and roots are thrown out from it at the expense of the matter

which the cutting contains; or when scars upon trees are seen to heal, i.e. to be covered by the deposition of new bark. In both these instances, as in the germination of seeds, the cells of the stem or cutting are placed under conditions which compel them so to act that matter is translocated to supply a pressing need. In the familiar method of propagating trees by burying a branch in the ground, as a "layer," it is customary to twist, or bruise, or cut the part which is to be buried, in order that roots may be thrown out at this point, and these roots are nourished by matters which are transferred from the bough, as well as from the parent tree also for a time. In pruning trees, it is said to be well to leave some shoots or small branches near the places where limbs have been cut off, in order that their leaves may "keep up a flow of sap" to hasten the healing of the scar; and it is an old observation, that, in grafting upon the bough of a tree, the scions will be apt to perish if too many of the old boughs are cut away. (Bacon.)

The familiar fact that trees, after having borne a heavy crop of fruit (or of seeds), are so much exhausted that they generally yield but little on the following year (or years), doubtless depends upon an actual using up of matters which the trees had accumulated before the time of fruiting. So too when gardeners wish to obtain especially fine specimens of fruit, they either pick off most of the blossoms from the tree, or they pluck off the larger part of the young and immature fruit, taking care to leave only a few individuals, which shall be nourished from the whole store of materials which the tree contains or can supply, or they pinch off the late-flowering shoots of melons and other vines in order that the fruit which has already set may profit by nutriment which would otherwise go to waste. Pea-vines also may be pinched in when they are too much disposed to run to leaf. Another instance where the translocation of matter is directed and controlled to a certain extent by human agency is seen in the European practice of girdling the branch of a grape-vine below a bunch of fruit, in order that the latter may grow to a large size, and that the process of ripening may be hastened. It is evident in this case that the constituents of the vine can no longer pass to and fro freely and easily at that place upon the branch where the bark has been removed, and it is to be inferred that only a comparatively small proportion of the nutritive matters which are formed in the branch can pass out from it into the vine proper. Hence they will natu-

rally accumulate in that one particular bunch of fruit to which they have easy access.

Maize-Cane and Sugar-Cane.

A still more remarkable example of the results of human interference is seen in a method of changing the stalks of Indian corn to a true sugar-cane by plucking off from the plant in midsummer all seed-bearing ears. "If the ears be removed promptly at the critical period all the vital energies of the plant become at once directed to the special work of storing up highly-organized food-materials [i.e. sugar] in the cells of the stalk. . . . The stalk is the storehouse, and under the new conditions imposed, that part of the plant passes through a supplementary stage of development. Its principal function then is to accumulate sugar."

By removing the ears from half-grown maize, the percentage of sugar in the stalks can be wellnigh doubled and the plant changed from a seed-bearing to a sugar-producing crop. It is thought indeed, that the "maize-cane" thus obtained may become as useful an economic source of sugar as the beet-root, or even as the true sugar-cane; for while the juice of ordinary corn-stalks contains at the utmost no more than 7 or 8 % of cane sugar, stalks from which ears have been removed betimes yield a juice that contains 13 to 16 %, i. e. as much as is usually contained in the juice of the sugar-cane of the tropics. It is to be noted indeed that the true sugar-cane is itself a plant which has been perverted in the course of ages from seed-bearing to a very different purpose, viz. the accumulation of sugar. "No variety of sugar-cane is known to perfect seeds or to produce anything like seed"; and maize in the secondary stage of development here described is likewise incapable of producing seed.

In view of these facts, F. L. Stewart[1] has maintained that the best method of managing Indian corn will be not to allow the grain to ripen as is now usual, but to remove and utilize the immature ears, and subsequently to manufacture sugar from the mature stalks. He would allow the plant to grow naturally until the grain has reached the "milky" stage, but has not yet passed in the least degree beyond it, and then he would pluck off from the stalks every vestige of an ear.

After the removal of the ears there will still be a fortnight or more of hot August weather during which the plants will be occu-

[1] Science, 1893, 22, pp. 143, 157, 171.

pied in accumulating sugar, the manufacture of which might regularly be begun by the first week in September. The immature ears may be preserved in silos at the moment when they are gathered — or the grain might be removed from the cob by means of special appliances, and be dried methodically. In either event it would be a valuable fodder. The leaves on the maize-cane and the tops of the stalks would naturally be saved as ensilage when the cane is harvested. To facilitate the gathering of the ears, there might be left open lanes at regular intervals between the rows of corn, through which narrow carts could be driven.

Sprouts and Suckers from old Trees are Feeble.

It is noticeable in some cases that the movement of nutritive matters from one part of a plant to another seems to be less easily accomplished in old and enfeebled plants than in those which are young and vigorous. Thus, a sprout or sucker starting from the stump of a very old tree is apt to grow but feebly, and to be worthless, economically speaking, apparently because, unlike a seedling, the sprout does not take on a new life of its own, but continues to be fed through the old indurated and enfeebled roots and root-cells of the original tree. It is to be presumed that, if the trees on sprout land (coppice) were allowed to grow large enough to be used as timber, the new sprouts, springing from stumps so old, would be less vigorous and less useful than those to which we are accustomed.

Marshall said of this matter, in 1796, "A young wood may be 'sprung' afresh with a degree of certainty. But perhaps there is danger as well as difficulty in regenerating an old one." It appears, indeed, that foresters are familiar with this difficulty. Thus, T. Hartig, in his "Forstliches Lexicon," Article "Stockausschlag," says, "Nearly all kinds of deciduous trees when cut down before they are 30 or 40 years old throw out sprouts from their stumps. But few kinds of trees give good sprouts when felled at a greater age." In actual practice, near Boston, it is usual to cut off the trees on sprout-land three or four times every century, and to use them for firewood. Arthur Young wrote of this matter as follows: "If willows, poplars, ash, etc., are planted for timber to be cut at whatever age, 10, 20, or 30 years, when cut, the stools will throw out many shoots; but let it not be imagined that these shoots will ever again become timber. They will never be anything but copse-wood, and attended in future with no more than

the copse profit, which is [in England at that time] not half that of timber. . . . Timber of any kind will pay double and treble what the shoots from any stools in the world will do.''

When a potato lying in a dry place "sprouts" in the spring, there is evidently a movement into the succulent sprout of some of the water which the potato originally held, as well as of nutritive matters which are dissolved in that water. Meanwhile the body of the potato is seen to wilt and to become dry and shrunken because water has passed out from it. The same thing occurs, of course, in the sprouting of many other kinds of tubers and bulbs. The most familiar example of all is seen in the transference of matter from the quiescent or dying older leaves on herbaceous plants to those parts of the plant where growth is new and active. Nothing is more common than to see the lower leaves of a plant curl up and drop off at the very time when the upper leaves are in a condition of vigorous growth, and it is now well known that there is an incessant transference of matter from the older to the newer parts of plants.

It is noticeable that each leaf on a plant runs its own course of life, and contains different proportions of chemical substances at the several stages between youth and maturity; thus, in tobacco leaves, Mueller-Thurgau found very different amounts of starch and sugar at different stages of growth, as will appear in the following table: —

There was contained in the dry matter of	Starch. Per cent.	Sugar. Per cent.
Unripe tobacco leaves	31.4	1.2
Nearly ripe " "	38.4	1.0
Fully ripe " "	42.6	0.8

So, too, in preparing certain crops for market, processes of fermentation occur which may remove one or another of the chemical constituents of leaves. This remark is true of hay, as will be seen in a subsequent chapter, and it is conspicuously true of tobacco, which has to be carefully cured to make it merchantable. While fresh, ripe tobacco-leaves contain much starch, together with a considerable amount of sugar, fermented tobacco usually contains very little starch, and no sugar at all. In fresh leaves, the starch may amount to from about a third of the dry substance in the leaf to almost one-half; and if such leaves are dried rapidly, they will be found always to contain starch, sometimes in no inconsiderable quantity, and some sugar also. But by slowly

drying the leaves, as in the process of curing tobacco, most of the starch will disappear in the course of a few days, and none of it can be found after the lapse of some time, unless, indeed, the drying has been too rapid. All the sugar disappears, also, by way of fermentation, as has been said. Another effect of the fermentation of tobacco is to change albuminoids to amids. (Fesca.)

Development of Roots.

As has been insisted already, most plants in their earliest youth, immediately after the very first leaves have appeared, develop a comparatively large mass of roots before much growth can occur above ground. The course of growth of grain, for example, is first a number of low-lying leaves, while a great complex of roots is in process of formation, and then suddenly the stalk of the plant shoots up all at once almost to mature stature. This peculiar habit of growth may be well seen in winter-rye, which is a crop that makes ready in autumn for the very rapid development of leaves and stalks in the next spring.

Probably the roots of most annual plants are completely developed by the time the formation of the fruit has begun. With biennial plants, also, this phenomenon of a great development of roots during the earlier periods of growth is very evident. The common weed, burdock, for example, offers a conspicuous instance of root-development while the plant is very young, to be followed by the growth of a number of very large leaves; while it is only in the second year that the tall, branching stem and the seed-burrs are produced.

With perennial plants, moreover, the growth of a new suit of roots in the spring of each year precedes any rapid growth above ground. Indeed, Hellriegel, who grew clover two years in succession in glass jars, observed that a new course of life set in every time the plants were mown. First of all, an energetic movement of life was seen below ground, where a multitude of new root-fibres were sent out into the earth in all directions, and subsequently a new growth of leaves and stalks appeared; i. e. the growth above ground followed the development of the roots in due course.

Storing of Food for the next Year's Use.

In general, the first development of roots and leaves in biennial and perennial plants does not differ especially from that in an-

nuals, but toward the end of summer such plants proceed to store up in their stems or roots a great quantity of nutritive matters which shall serve during the next spring for nourishing the first shoots and leaves and rootlets, much in the same way that the matters in a seed nourish the young plant at the time of germination. The course of growth of a seedling beet or turnip, for example, is, first, rootlets enough to support the leaves, which soon grow luxuriantly and collect much food from the air. Thanks to the activity of the leaves, large quantities of nutritive matters are sent down to the roots, and stored there to be used by the plant next year. There are experiments of Anderson which show quantitatively the relations which were observed to subsist in the turnip between leaves and "root" at different stages of the plant's development. The figures given in the following table relate to the crop obtained from an acre of land: —

Date.	Age of Plants. Days.	Weight of Leaves. lb.	Weight of Roots. lb.
7 July	32	219	7
11 August	67	12,793	2,762
1 September . . .	87	19,200	14,400
5 October	122	11,207	36,792

Reserve Food stored in Trees.

In like manner, it has long been known that in deciduous trees large quantities of starch and other matters are stored up within the tissues of the stems and roots towards the end of summer and in the early autumn. Before the leaves of trees fall at the approach of winter, they have given up to the twigs and stem a large proportion of the starch and albuminoids, as well as the potash, phosphoric acid, and other useful ash-ingredients, which were contained in them previously. But in the next spring, when returning warmth excites the tree to renewed vigor, the starch which has thus been stored is changed to sugar, or dextrin, or gum, and these substances, together with the other matters that were laid by, serve for the development of new foliage. In evergreen trees there is less need that starch should be stored in the wood, because such trees are constantly covered with foliage, and have no such marked period of rest as the deciduous trees. That active chemical action occurs in trees in the early spring, even before the appearance of their leaves, is made evident by the fact already mentioned that large quantities of oxygen are absorbed at that season by the leaf-buds. It has been noticed, indeed, that at

low temperatures more oxygen is absorbed than there is carbonic acid given off. But even in January, when, as he says, the life of the buds was benumbed, and their respiration most feeble, Moissan obtained in ten hours 17 cc. of carbonic acid from a horse-chestnut twig which weighed 100 grm. and had two buds upon it. In April, when the reserve matter stored in the tree was undergoing change, and the buds were swelling and the sap running, he found that more than four times as much carbonic acid was given off from a similar 100 grm. twig. He got, namely, 76.3 cc. of carbonic acid in 10 hours. In other experiments, 500 grm. of buds collected in April gave 98 cc. of carbonic acid in 10 hours at 59° F, and at 86° the same weight of buds gave 202 cc. of carbonic acid. It appeared that the most vigorous action occurred in the buds proper before the young leaves had emerged from them. In experiments made a month later than the foregoing, at a time, namely, when the leaves had unfolded completely, it was found that respiration was much less energetic than it had been in the buds.

There are many trees which store up starch, etc., in the winter for the next year's use. Desbarres found in peeled wood from young twigs of Rhus elegans in the winter, and in the spring after buds had unfolded, the following substances: —

	Winter.	Spring.
	%	%
Dry matter	72.16	66.70
Ashes	1.60	1.23
Starch	17.31	1.57
Albuminoids	9.42	2.25

The sugar obtainable in the spring from maple-trees comes from starch which was stored away in the wood towards the close of the previous year. Hartig and others have observed that much starch is stored up in this way in a great variety of trees, and that the trees yield a sweet sap in the spring.

Reserve Food in Root-crops, Cabbages, etc.

Several familiar crops consist of reservoirs of nutritive matters which have been stored away for the next year's use by biennial plants. Such plants as beets, carrots, turnips, parsnips, salsify, onions, and potatoes, for example, are in this category, and so are cabbages, Brussels sprouts, and kohlrabi. During the greater part of the summer the leaves of these plants elaborate food, and transfer it to the underground tap-roots or tubers, or to the

"heads" of cabbages or the like, which accordingly grow to a large size by the time when cold weather sets in. Next year, if such roots are placed in the earth, the matters which were accumulated in them during the previous year are immediately put to use for the production of a flower-stalk which grows strong and tall and bears leaves and flowers and seeds in due course.

It is to be noted, however, that the materials thus stored in roots are not sufficient of themselves for the best possible production of seeds in the following year. Experiments made in Germany on sugar-beets have shown that the plants produce much new substance in the second year of growth, and that it is advantageous to set out seed-beets in a rich soil, or in a soil that has been well manured. (Strohmer.) It will be noted also that the process so familiar in domestic horticulture, of growing hyacinths and other bulbs in mere water, has for its object the production of flowers merely, not of seeds.

It is noteworthy that the value not only of roots and tubers but of many other crops, depends absolutely upon the reserve matters which have been stored in them for the use of the next year's plant, but which are seized upon by man for his own support. Grain-bearing plants and pulse fall into this category as clearly as do cabbages and potatoes, and so do the sugar cane, sorghum and the sugar-beet, as well as the plants from whose seeds or fruit oil is expressed.

When to Transplant Trees.

It is evident that in transplanting trees it will be best to move them at a period when they are in repose; that is to say, either in the autumn or in the spring, when they are, comparatively speaking, quiescent, in that the movements of matter within them are slight and feeble, and that they are neither growing vigorously nor transpiring great quantities of water. But a consideration of the facts just now set forth will show at once why it is that gardeners in a climate as rigorous as that of New England very much prefer to transplant trees and shrubs in the spring rather than in the autumn. In the autumn the tree has adjusted itself to certain conditions, and has come to rest for the term of hibernation. If disturbed at that season, it has no opportunity to readjust itself to the new conditions, or to recover from any accidental injuries which it may receive. But in the spring, no matter where the plant may be placed, it is ready to begin a new course of life,

and to feed upon the reserved matters which are stored in it. Hence a tree will suffer comparatively little when carefully transplanted at this season.

In warmer climates there are other considerations which may sometimes cause the autumn to be regarded as a better season than the spring for transplanting trees, as in regions where the ground hardly ever freezes, and especially in those where spring droughts are to be feared. Gasparin insisted long ago that for the South of France, on soils not unduly wet, the autumn is the best season for transplanting, for, as he says, the soil is still warm enough and moist enough at that season to permit the transplanted tree to adjust itself to the changed conditions. Some new roots are formed, and moisture enough is sent into the tree to enable its buds and leaves to develop naturally in due season. But spring planting would be best, even at the South, on land so wet that the roots of a tree set out upon it in the autumn might be macerated by the moisture and caused to decay.

In order to success with olives and the evergreen oak, their leaves must be plucked off before the moment of transplanting, so that the transpiration of water shall be checked. (Gasparin.) Mulberry-trees also are sometimes transplanted in Southern France, on irrigated land, as late as the month of May, at the time when they are stripped of their leaves.

Durability of Timber.

As was pointed out long ago by Chevandier and by Hartig, the durability of timber may depend in no small degree upon the proportion of nitrogenous matters and of starch which is contained in it. These substances and their analogues are much more nutritious than mere woody fibre is, and they are, in fact, the favorite food of the larvæ of many insects which destroy wood, and of numberless fungi which cause wood to decay. Other things being equal, timber will naturally last longest if the tree is felled at a season when the wood contains the smallest amount of nitrogenous matters, sugar, starch, and other matters which are fit to feed insects, fungi and worms. It is for the purpose of rendering these substances inedible or poisonous that wood is sometimes impregnated with chemicals to preserve it.

The foregoing idea was expressed in a manner by Pliny, as follows: "The proper time for cutting a tree is when the seed is ripe. . . . In general it is to be looked upon as quite sufficient to

use all due precaution that a tree is not rough-hewn before it has borne its yearly crop." According to Chaptal, Julius Cæsar found that ships were not durable when built of timber from trees which had been felled in the spring. Vitruvius also, the Roman architect, held that "trees should never be felled in the spring, because at that period they are, as it were, pregnant, and communicate their natural strength to the yearly leaves and fruits they shoot forth." He directs that, "in felling, the proper way is to cut through at once to the middle of the trunk of the tree, and then leave it for some time, that the juices may drain off. Thus, the useless liquor contained in the tree running away through the external rings, all tendency to decay is removed, and it is preserved sound. After the draining has ceased and the tree has dried, it may be cut down and considered quite fit for use." All of which consists better with what is now known to be true, than does his idea that trees should be felled in winter, "because the force of the keen winter compresses and consolidates the timber." Pliny also remarks that "some persons cut round the tree as far as the pith, and then leave the tree standing so that all the juices may be enabled to escape, — and the practice is by no means without its utility."

Firewood may differ from Timber.

It will be noticed, however, that there are two distinct points to be considered, according as the trees are to be used for building purposes or as fuel. It is probable that, generally speaking, winter may be the best season to cut wood which is to be burned as fuel. Any given number of sticks of cord-wood that have been cut in the winter would naturally weigh more, and contain more combustible, heat-producing matter than the same number and kind of sticks cut in the summer, after the starch, etc., had passed out from them; but this question of fuel is evidently different from that of the durability of timber. In New England it happens as a matter of course that trees are commonly felled in the winter, no matter for what purpose the wood is to be used, simply because labor is to be had more cheaply at that season than in the summer, and because logs can be hauled out from the forest much more readily upon sleds than by means of wheels. In any community chiefly occupied with farming, trees would naturally be felled in the winter, — a season of comparative leisure. But in regions devoted wholly to forestry summer felling must often be practised. It is

said, indeed, that it has long been customary in the Alps, and in some of the countries of Northern Europe, to cut down in summer the resinous trees which abound there. The English writer, Loudon, has supposed that this summer felling was "of necessity" (!), because in the winter the woods are so blocked with snow that felling is hardly practicable.

It is possible, perhaps, that it might not be easy to "season" some kinds of wood properly in the heat of midsummer, for moist, freshly-cut wood might then be attacked by the micro-organisms which cause decay, simply because the temperature was particularly favorable for their development, even though the wood contained at that time a minimum of saccharine and starchy matters. But, on the other hand, the risk of injury from insects and worms would be greatly lessened, and there can be little doubt — speaking in general terms and looking from the scientific point of view — that for timber trees summer felling should be preferred. If the cost of labor be left out of consideration, there can be little question that in northern climates timber of the highest degree of durability would be secured by felling trees in midsummer, or perhaps just before midsummer, after the winter's store of starch, albuminoids, etc., has been measurably exhausted in the making of buds, leaves, twigs, flowers, fruit, and new wood. Payen, who found much starch, in winter, in the wood of an ash-tree, has remarked that, in France, it is much more advantageous to cut ash poles in the month of May than at an earlier season, because by that time the reserve of starch [etc.] has passed out from the tissues of the wood, and has left the wood much less exposed to the attacks of insects.

Barring the risk of the attacks of microscopic fungi in warm weather, it is evident, even as regards fuel, that it may sometimes be advisable, for the sake of durability, to cut down in summer rather than in winter those kinds of trees which have wood particularly apt to decay quickly when exposed to damp air in warm weather. Arthur Young, in his "Travels in Ireland," cites evidence that particularly durable fir timber may be got by cutting down the trees in June and letting the logs lie in water for three or four months.

Barking of Timber-Trees.

The idea expressed by Vitruvius and by Pliny, that by partially cutting timber-trees the wood may be exhausted of hurtful

"juices," has been curiously illustrated by old English experience. In 1640 Parliament passed an act concerning tanners, etc., which enjoined that "No person shall . . . fell or cause to be felled any oaken trees meet to be barked . . . but between the first day of April and the last day of June." It was directed, furthermore, that no purveyers of timber to the Crown shall fell or cause to be felled for the use of the King's Majesty any oaken timber-tree or trees meet to be barked but in barking time; or shall in any wise take or receive any manner of profit by any lops, tops, or bark of any trees to be taken by them; or shall in any wise take any more of any tree than only the timber, to be used upon or about the King's ships. But, as Plot[1] observed, while this law was actually in force, the felling of oak-trees between the first of April and the last of June, when the sap is up, and the bark will run, causes the outside of the timber to rot away quickly and to grow worm-eaten; whereas these being felled in or near the winter, and having stood naked all the summer drying in the sun, become in a manner as hard and sound without as within, being, as it were, all heart, and not subject to worms. Plot makes particular mention of "several oaks that stood naked, divested of their bark, which they told me would not be felled till Michaelmas (Sept. 29) following at soonest, or perhaps not till midwinter or the ensuing spring."

This matter was experimented upon by Buffon, who in May, 1737, caused the bark to be removed from several large standing oaks, and noticed that the trees died in the course of three years. On then cutting the trees down, the outer wood was found to be hard and dry, and very strong. Buffon concluded that "timber which has been disbarked and dried while standing will weigh heavier and prove stronger than timber cut in the bark." Indeed, several Continental writers have recommended this method of felling as if it were economically practicable, and it has been said of larch, in particular, that the wood is greatly improved when seasoned in this way. It is hardly to be supposed that any method of felling trees which is so circumstantial, time-consuming and costly as the foregoing can ever be commonly practised, but from the theoretic point of view it is evident enough that the peeling off of bark from the standing tree in the spring, and the felling of the tree itself some months afterward, — when sugar, starch, and

[1] Robert Plot, "Natural History of Staffordshire," 1686, p. 182, cap. 9, § 87.

other equally decomposable matters have passed out of the sapwood, — are acts well suited for the procuring of durable timber. They illustrate capitally a fundamental scientific principle, which should always be kept in view.

Pruning Trees, Clipping Hedges, etc.

In precisely the same sense, Marshall assures us: "It is well known that cutting trees while in a state of growth is injurious to their future progress, being, it is understood, prejudicial to their roots." Provided there is no exhaustion by bleeding, the stump of a tree which has been cut down during the period of hibernation, when its roots are charged with the nutritive matters then held in reserve, will be better able to send up a vigorous sprout in due season than can possibly be the case if the tree is felled after leaves and new twigs have formed upon it, and have used up a good part of the reserved nutritive matter. There is, as Marshall says, "a judicious moment for cutting hedges and underwood (from which sprouts are to grow), viz. when the sap has begun to rise, but before any part of it has been exhausted, and perhaps this time is when the tree is beginning to bud."

The same reasoning will apply, of course, to the pruning of fruit-trees. It is, in fact, a maxim of practical experience, that if trees are pruned in early winter, when they are dormant, the growth of those boughs which are left will be particularly vigorous in the spring: manifestly because the reserve store of nutriment in the tree will be expended solely for their benefit. Conversely, it is held that if trees are pruned at a time when they are growing freely, their growth will be retarded, not only because they are now deprived of many leaves which had been occupied in gathering food for the use of the whole tree, but because some food and force will naturally be expended in the effort to heal the cuts and scars which the pruning has occasioned.

As was just now suggested, it may happen that the stumps of trees felled late in the winter bleed so freely in the early spring, before any shoots have started, that they eventually send up less vigorous sprouts than do the stumps of trees which have been cut so late in the spring that sprouts can start quickly enough to put the saccharine juices to profit, and thus hinder them from running to waste. The same thing is seen in pruning vines and some kinds of fruit-trees. There will not be any bleeding if the pruning is done in the autumn, for in that case the wounded surfaces have

time to become indurated before the sap again begins to flow; nor will any serious bleeding be apt to occur in the spring if the pruning is done late enough. In any event, the general rule holds good that midsummer is a fit season for destroying trees by felling them.

Part of the Reserve Food in Trees may long be held.

From the observations of R. Hartig it appears that the reserve starch stored up in a tree on any given summer and autumn is not necessarily wholly dissolved and consumed during the next growing season. He finds that a very small quantity of reserve material — no more, for instance, than may be contained in the cells of one or two of the newest annual rings of the tree — is sufficient to start the young shoots in the spring, and to maintain them until the new leaves are large enough to get food from the air. He argues furthermore, that a large proportion of the starch in trees is held in reserve until the bearing year, i. e. until the year when flowers and fruit are produced, and that then the store both of starch and of nitrogenous matters is rapidly used up. In beech trees which he examined in 1888, after they had borne fruit, Hartig found that from one-half to two-thirds of the reserve of starch had disappeared from the wood, and that the percentage of nitrogen was in most places less than 0.01, whereas in 1886 the wood contained 0.098 to 0.392% of nitrogen, according to the position from which the samples were taken.

The slowness with which the reserve food in trees is used up is illustrated by the experience of the makers of maple-sugar, some of whom have noticed that, when care is taken to keep the sap-pails "sweet" and free from ferments by scalding them frequently and thoroughly, sugar may be made until the leaves on the tree "have grown to be as large as the palm of a man's hand." (J. C. Andrews.) Ordinarily it is taught that maple sap drawn from the tree after the buds have begun to open is useless for sugar-making, because of a peculiar taste called "buddy," but it is said that the real trouble is that when the weather has become warm enough to start the buds freely, there is so great a liability that the sap will turn sour that the trouble in making sugar is greater than the profit.

Beside starch, various other matters are thus stored, notably albuminoids, fatty oils, and amids, as has been said, together with substances, related both to starch and to cellulose, which have

been classed as hemi-celluloses and pentosans. In some plants, such as the sugar cane, sorghum, Indian corn, and beet-roots, starch is replaced by cane-sugar, and in the onion by a variety of grape-sugar. In the roots of other plants, such as the dahlia, and others of the Compositæ, inulin is found instead of starch.

Flowers and Fruits are Derivative.

It is noteworthy that most spring blossoms, such as crocuses, tulips, hyacinths, apples, dandelions, and what-not, appear either upon plants that are provided with bulbs, tubers, or root-stalks, or upon trees and shrubs in which nutritive matters have been stored away in the previous year. Generally speaking, such plants as these can sooner proceed with the business of blossoming than can annuals, the seeds of which sprout in the spring; for some little time is needed in order that the new plant may develop roots and leaves, and collect materials for the elaboration of flowers and fruits, before any blossoms can appear upon it. (Grant Allen.) It is true in general, not only of biennial and perennial plants, but of annuals also, that flowers and fruits derive most of their constituents not immediately from the air or from the soil, but either directly or indirectly from the leaves, in which matters taken in from the air or from the soil have been transformed into organized substances.

Roots and Tubers are fed by Leaves.

The importance of having well-developed leaves in order that a crop may succeed, has been illustrated repeatedly in experiments that were made many years ago in the hope of checking the potato-rot. The idea was, that if the potato-vines were mown immediately after the fungus which causes the disease had appeared upon them, the progress of the latter might be checked, and a considerable harvest of tubers still be obtained. There is probably something of truth in this conception in so far as it relates to the saving of tubers which have already grown before the fungus appears, and, were it not for the cost of the operation, it might be well to mow potato-vines as soon as it has become plain that the rot-fungus has attacked them. But it must be remembered that the tubers will practically cease to grow when the vines have been cut off, either by means of a scythe, or through the destructive action of the rot-fungus. By removing the leaves, the plants are deprived of the organs in which matters are elaborated for increasing the size and weight of the tubers. The following experiment by Dietrich may be taken as a sample of many.

In a potato-field which had been planted on May 20 he staked out four plots, each containing 150 plants, and he tested and mowed the plots at four different periods, as follows. Ten weeks after planting (i. e. on July 29) 50 plants were dug up on Plot I, and the vines of the other hundred plants were cut off at a short distance above the earth. In this case new shoots were speedily thrown up, but they were afterwards attacked by the rot-fungus. Twelve weeks after planting (August 16) 50 plants were dug up from Plot II, and 100 plants mown; and fourteen weeks after planting (i. e. on August 30) 50 plants were dug and 100 mown on Plot III; but no new shoot came up on either of these plots. Eighteen weeks after planting (Sept. 13), the vines on Plot IV were found to be dead. Indeed, they had disappeared so completely that there was nothing left to cut; hence the tubers of 50 plants were dug up at that time, while those of the other 100 plants were left in the ground. Up to the 16th of August the growth of the crop appeared to be excellent; but at that time it became evident that the rot-fungus was firmly established upon the plants. At the time (August 30) when Plot III was mown, the vines were all in a very bad condition, and some of them were already totally destroyed as a result of the action of the fungus. On the 4th of October the several lots of 100 tubers that had been left in the ground on the different plots were dug up and weighed. In the table the results are all stated in terms of 100 plants, merely for the sake of convenience: —

100 Plants pulled up on	Yielded lb. of Tubers.	From the hills where 100 plants were mown on	There was harvested on Oct. 4, lb. of Tubers.
29 July . . .	20	29 July . . .	31
16 August . .	61	16 August . . .	74
30 August . .	99½	30 August . . .	65
13 September.	71	13 September . .	78

No rotting potatoes were found where the vines had been mown, excepting one-quarter of a pound in the case where the vines were mown on July 29. But small quantities (1 or 2 lb.) of the potatoes that had been pulled up were found to be rotten at the time of weighing.

Ten weeks after the planting of the potatoes, which were of a later variety than is usually grown nowadays, it was observed that no more than half the normal number of tubers had grown, and that these tubers were small, and hardly half as heavy as they

should be. The disease was even then at work, and all the subsequent trials were vitiated by the presence of it. It was evident that, as soon as the potato-vines were attacked by the rot-fungus, they ceased to be able to supply materials for the development of the tubers, and that consequently no harm was done by cutting the diseased vines away.

As is well known, many weeds can be destroyed by preventing the formation of leaves upon them. Thus even couch-grass may be killed by cutting away its leaves at or before the moment of their appearance above ground. To do this on small pieces of land, W. J. Beal turns up the soil with a shallow furrow as soon as the grass first shows some green leaves in the spring, and he subsequently cultivates or hoes the land every 3 days without waiting for leaves to show themselves. He has never failed to eradicate the grass in Michigan, by this method, by the 10th or 15th of June, i. e. in time for the planting of some kind of a crop. He finds that in the spring, at least, couch-grass can be killed more quickly and more cheaply when the weather favors rapid growth than in dry weather.

Root-Crops grow large when Time permits.

It has been noticed in England that late varieties of plants are often more productive than earlier varieties, when all are treated alike to moderate supplies of manure, because, the longer the time during which the leaves of a plant can act to draw food from the air, so much the larger will be the crop which they can produce. This point is conspicuously illustrated in California, where enormously large beets, carrots, turnips, and pumpkins are obtained sometimes, when the crops are left standing in the fields during a mild winter, and the plants have opportunity to grow and to store up reserve food during ten months, i. e. from the time they were sown until the land is cleared for planting the next year's crop.

According to Russell, some part of the success obtained by seeding wheat very thinly, and "cultivating" it, is to be attributed to the fact that the term of growth of the crop is lengthened. Such plants grow large and late, and form many leaves from which a correspondingly large number of seeds are finally developed. In this point of view, thin seeding may be regarded as a means of developing large amounts of leaf-surface by means of moderate supplies of water and manure. It is a method of economizing moisture and plant-food; whereas thick seeding works to limit the

amount of water and manure that can be acquired by any one plant, and so acts to check growth and to hasten the tendency to flower, and thus leads to the early harvesting of a comparatively small quantity of grain from each individual plant.

Leaves of Root-Crops as Fodder.

Formerly, the leaves of root-crops were highly esteemed, in Europe, as fodder. It is said, indeed, that in the beginning beets were cultivated for the sake of their leaves. Even after the recognition of the fact that it is the roots of beets and turnips which are of primary importance, it was still thought that considerable gain might be got by pulling off the lower leaves of the plants from time to time for the purpose of feeding cows or hogs. The practice was soon condemned by intelligent farmers, and has long since ceased to be held in respect, though doubtless it is still persisted in by peasant proprietors in some localities. In such cases, the question is always in order, whether the good got by the animals from eating the leaves is not more than counterbalanced by the harm done to the crop by their removal. This remark will apply, of course, to a custom said to be prevalent in some parts of the South of France, of allowing flocks of sheep to eat off the leaves of grape-vines after the vintage, though, as Muntz has urged, this practice need not be injurious, provided the wood of the vine-shoots has become thoroughly ripe.

Many methodical experiments have been made by different observers to test the effect of removing leaves from beet-crops, with the result that the yield of roots was almost always decidedly diminished when sound leaves were plucked off. Fittbogen, for example, has shown that, no matter at what period of growth the leaves are removed from beets, smaller crops of roots and smaller amounts of total crop are obtained than when the plants are left to grow normally. Naturally enough, less harm is done the later in the season the leaves are plucked, and it has sometimes been observed that little or no harm is done when very old leaves which have begun to wither are pulled off late in the season. Schacht noticed long ago that when some of the leaves of beets are removed during growth the amount of sugar in the roots is diminished, and many manufacturers of beet-sugar have insisted that they will not buy beet-roots in case the leaves have been removed before the crop is ripe. Violette, and several other observers, have shown that both the total yield of beet-roots and the amount

of sugar in the roots may be very much diminished by removing leaves from the growing plants. In Corenwinder's experiments it appeared that sugar is formed in the beet-leaves, and that, as a rule, those plants which have large and well-developed leaves are richer in sugar than plants whose leaves are small or slender. In general, it may be said that he found the amount of sugar in beet-roots to be in direct proportion to the amount of leaf-surface of the plants.

Leaves of Root-Crops as Manure.

A subsidiary consideration which needs to be kept in view is the fact that the leaves of root-crops have considerable fertilizing value when they are left upon the land to be ploughed under. On highly farmed land in many localities beets are thought to be a good preparatory crop for grain, but it has been said sometimes of light land, that grain after roots may fail in case the tops have been carted off. Instances are upon record where no success was had on trying to grow wheat after mangolds so long as the beet-leaves were removed from the land; but on ploughing under a good dressing of the leaves, the difficulty was removed at once. This result is not surprising, in view of the large quantity of nitrates, as well as of other saline matters, which beet-leaves may contain. Indeed, when grown on fertile soils in France, the leaves of sugar-beets not infrequently become so highly charged with nitrates that they are unfit food for animals. It is said that serious results have occurred repeatedly on using such leaves as fodder. (Dehérain.)

Several comparative experiments made by a German farmer led him to conclude that beet-leaves really possess no inconsiderable amount of fertilizing power. When applied for sugar-beets, the leaves had a very favorable influence in so far as increasing the yield of roots was concerned, though, not unnaturally, the quality of the beet-juice was injured by the saline matters in the leaves. When applied for barley, beet-leaves increased the yield of straw, but the grain was lighter than was desirable. Dehérain has remarked on the fact that when the leaves of sugar-beets are left for some time lying in heaps upon the land at the time of harvest, the influence of the fertilizing matters which drain out from them may plainly be seen next year in the increased growth of the succeeding crop. Fodder-corn, for example, will grow particularly tall and take on a deep green color on the spots where beet-leaves

have lain. In the rainy northwestern counties of Scotland it is estimated that about four tons of tops to the acre are left by a good crop of mangolds or of Swedish turnips when the roots are taken up early in November; and it is said that the farmers there are very particular to have the turnip-tops regularly spread over the land immediately after the harvest, and ploughed in deeply, as a preparation for wheat. Heavy crops of wheat are obtained. But in the southern and middle counties of England the tops of root-crops seem to be much less efficient than in Scotland, and they are generally reinforced with artificial manures. It has been thought that this difference may perhaps depend on the quantity of tops, which is particularly large in moist climates.

Instead of regarding the leaves of root-crops as manure to be spread upon the land directly, they may readily be saved as ensilage at the time of harvest in cases where profit can be got by feeding animals. In some European localities, large quantities of beet-leaves have been utilized in this way, and there is small reason to fear that any harm can result if the fodder is employed judiciously. Boussingault's determination of the amounts of leaves, etc., left by root-crops and by potatoes, have already been given when treating of the rotation of crops. See "Amount of stubble, etc., left by fallow-crops."

The Plucking of Grape-Leaves.

In many localities, notably in Southern France, an impression has prevailed from time immemorial, that grapes may be made richer in sugar by removing the leaves of the vines so that sunlight may fall upon the ripening fruit, and H. Mueller has even urged that a large number of leaf-bearing shoots of the vine should be sacrificed during the ripening of the fruit, because these leaves require a large quantity of sugar for their development and for the support of their respiration. He argues that there need be no fear of causing too great destruction of assimilating tissues by removing the old leaves, since they no longer have much assimilative power, and are shaded by the upper leaves. But, as LeClerc and Gasparin, Comté and Nessler have shown, this idea is subject to limitations, and care must be taken not to remove too many leaves at any time, and not to remove leaves before the fruit has become tolerably well advanced toward maturity. Naturally enough, the amount of sugar in grapes would be diminished

if all the leaves were plucked from the vine before the fruit had ripened.

Muntz has found that while the temperature of bunches of grapes laid bare to sunlight may be even 30 to 35° F. higher than that of grapes shaded by their leaves, this elevation of temperature appears not to be accompanied by any increase of the amount of sugar in the grapes. Indeed it is not impossible that the high temperature may lead to a destruction of sugar, since the evolution of carbonic acid at 95° F. was found to be five times greater than at 63°. But he found that the acidity of the sun-heated grapes was less than that of shaded grapes, whence it follows that the plucking of the leaves may after all be a useful practice in regions where grapes ripen slowly, and where the wine is apt to be unduly acid.

A familiar example of the injury done by removing leaves is seen when caterpillars strip a tree completely in early summer. The growth of twigs comes to a standstill, and the whole strength of the tree is devoted to the production of a new crop of leaves; but the tree may die if it were feeble, or in case a new army of caterpillars should come on at midsummer to consume the new leaves. Another example of the significance of leaves is seen in the superior fertilizing power of clover-roots when the crop is allowed to grow to its full stature, instead of being kept short by pasturing it, as has been explained in the chapters on Rotation.

Harvesting of Forage Crops.

From what has been said of the function of leaves, it follows that a forage crop, like hay, should be cut not very much later than the time of flowering; or, rather, it should be cut before the seeds have made too much progress towards maturity. If grass were left until its seeds had actually ripened, a great part of the albumen, starch, and other materials which have value as fodder, would have gone out of the leaves and stem into the seeds, and the larger part of the plant would be transformed to the condition of effete straw. But the seeds may easily be lost, either by dropping out of the hay, or by passing undigested through the stomachs of the cattle, or by being eaten by mice and weevils. When this country was newer than it is now, it was a constant subject of remark among farmers, that timothy is apt to spring up on wild wood-roads where horse-dung has been dropped.

It is possible to harvest some kinds of crops at a moment when

the seeds have become mature enough to be used as seeds, while the leaves are still fresh enough to be used as fodder. Oats are often mown so early that the straw retains no small store of nutriment and is freely eaten by animals; and Gasparin says that, in some of the Swiss cantons, it is customary to harvest the bean-crop while the seeds are still green, in order to obtain a highly nutritious haulm for fodder.

In general, it will be best not to mow grass at the moment of flowering, but soon after the seeds have begun to form; that is to say, while the seeds are still soft and watery, for the sum total of nourishment in the plant will then be larger than when the plant was in flower. But, practically, care must be taken not to delay too long, because of the tendency of the seeds to ripen at the expense of the stalk after the harvest; and because of the fact that the lower part of the grass-stems begins to deteriorate immediately after the plant has flowered, that is to say, as soon as the seed begins to grow at the expense of the matters in the stem.

The oat-plant affords a striking instance of the liability of hay to undergo this kind of deterioration. Cut soon after flowering, the entire plant is greedily eaten by cattle, and it constitutes an admirable kind of forage; but after the grain has ripened, oat-straw is not very much better than any other kind of straw.

In practice, however, it is usually thought best to harvest the oat-crop rather early, because the oat-grains are attached to the plant by very slender threads, and much grain might be lost by the breaking of these threads in case a high wind should blow upon a standing ripe crop. As a consequence of this early harvesting, — and of the somewhat leafy habit of growth of the plant, — oat-straw is commonly rather better fodder than the straw of wheat, barley, or rye. It is noticeable withal, as regards the crops last named, even when they have been allowed to become thoroughly ripe, that the tops of the stalks still retain much nutritive matter and are freely eaten by animals accustomed to such food, although they may reject the buts.

There is no need to insist that the ripe oat-crop, that is to say a mixture of ripe oats and dead straw, would usually be a less advantageous kind of fodder than oat-hay cut at such a stage of growth that pretty much all of the nutriment of the ripe crop would be evenly distributed in every part of it. It is true enough that by passing the ripe straw through a hay-cutter together with

the oat-grain, and steaming the mixture, an excellent fodder could be prepared; but it would not be much better than the oat-hay, and it would be more costly.

It should be clearly understood, however, that in no case, either from the ripest straw or from dead autumn leaves, have the nutritive and fertilizing constituents passed completely out from the older parts of the plant, for the walls of their cells, or a part of these walls at least, together with some of the useful matters proper to them, must necessarily remain behind in any event, and a small part of the contents of the cells must remain also.

Harvesting of Grain.

With regard to the phenomena which determine the times of harvesting grain-crops, it is a matter of familiar observation that the standing crop ceases to grow soon after the ears have fairly formed. It is evident enough that from this time forward the grain ripens at the expense of the leaves and stalks. Hence the common custom of farmers to cut grain before it is fully ripe, and to leave it to ripen in sheaves and stooks, in order to avoid loss by shaking. It was a maxim of the Romans, even, that it is better to reap grain two days too soon rather than one day too late. Care must be taken, of course, to keep the mown grain dry — or, rather, to avoid wetness and dampness — during the ripening process. To this end it is recommended (in rainy countries) to cut the crop in fair weather, and to leave the sheaves open and untied during some hours in order that the plants may be dried out superficially by sun and wind; to make small sheaves that can be tied with a single length of straw; never to leave the sheaves lying upon the ground over night, but to set them up securely in small stooks so placed that they shall be freely exposed to sun and air. After the heads have fairly formed, it is little matter whether the plants remain connected with their roots or not. In either event, it can be seen that the stalks gradually dry up and change to straw, from below upwards.

These changes, though less emphatic in degree, are similar in kind to those witnessed in the experiment of Boussingault, where oat-plants, taken from a field when in blossom, and thereafter kept in distilled water, ripened a number of seeds of good quality; or in the experiment of Knop, who found that a maize-plant, grown by way of water-culture, had taken up at the time of flowering enough matter to enable it to perfect its fruit. The plant in ques-

tion produced and ripened a perfect ear of corn, although after the time of flowering it received no nourishment whatever other than what it could get from atmospheric air and pure distilled water. The details of the changes which plants undergo in ripening have been carefully studied by several chemists, particularly with regard to the oat-plant, under which head they will be considered more fully.

Dead-ripe Seeds the best for Sowing.

The significance of after-ripening for the formation of perfect seeds has been studied by Hellriegel in connection with the question as to the influence of ripeness on the germinative power of seeds. He selected a number of rye-plants, from a good field of this grain, at five different periods of ripeness. 1st. On June 26, when both grain and plant were still completely green, and the seeds very small and watery. They yielded a clear liquid when pressed. 2d. On July 3, when the plant was still green, though the seeds were large. They yielded a milky juice. 3d. On July 10, when the straw had begun to be yellow, and the seeds were full of starch, though still green and very soft. 4th. On July 18, when the straw was yellow and rather dry, and the seeds hard and no longer juicy (yellow-ripe). 5th. On July 30, when both straw and grain were dry, and the latter much inclined to shake out of the ears (dead-ripe).

Each of these five collections was divided into four portions, as follows: 1st. A quantity of the grain was removed completely from the plant at the moment of collection, so that the seeds could thenceforth get nothing from the plant. 2d. A number of ears were cut off and tied up in bundles. Here a small amount of after-ripening was possible, at the expense of the chaff. 3d. A number of stalks were cut off several inches above the earth, to imitate the ordinary process of reaping, and then tied in sheaves. Here after-ripening could occur, as in ordinary field practice. 4th. A number of plants were dug up so as to leave as many as possible of the roots attached to the stalks, and the plants were then placed with their roots in distilled water; the idea being to facilitate, in so far, the process of after-ripening. At the end of September all the seeds were removed from the plants, and parcels of them were sown in pots and in the field at the beginning of October. Each of the parcels sown in pots contained 100 seeds, and those sown in the field contained 60 seeds. Two kinds of soil

were chosen, one a rich garden-earth, and the other a poor sandy loam. So that each of the trials was duplicated. The seeds of the first collection were diminutively small, and even those of the third collection were much shrivelled. The following table gives the absolute weight in milligrams of 100 of the air-dried seeds as collected at the several stages of ripeness above described: —

	I.	II.	III.	IV.	V.
Seeds removed immediately from ears .	1043	1466	1837	2029	2223
Seeds left in the ears	1058	1483	1851	2030	2225
Seeds left attached to the straw	1131	1493	1862	2030	2228
Seeds left on plants whose roots were placed in water	1379	1544	2022	2107	2233

Whence it appears that the seeds of the first collection had acquired less than half, and those of the second collection hardly two-thirds, their normal development.

The comparative heaviness of the several parcels is shown by the following table, which gives the specific gravities of the air-dried seeds, at the several stages of ripeness, as before: —

	I.	II.	III.	IV.	V.
Seeds removed immediately from ears	1.165	1.260	1.260	1.280	1.290
Seeds left in the ears	1.165	1.270	1.280	1.290	1.290
Seeds left attached to the straw . .	1.165	1.260	1.270	1.290	1.290
Seeds left on plants whose roots were in water	1.230	1.270	1.280	1.290	1.300

The following tabular statements give the average percentage of seeds which germinated and grew when sown in jars of earth.

A. Seeds that were removed immediately from the ears: —

I.	II.	III.	IV.	V.
$4\frac{1}{4}$	5	$9\frac{1}{4}$	36	84

It appears clearly that in the earlier stages of their development the seeds have very little germinative power; that this power increases with the development, and is at its best when the seeds are fully ripe. Indeed, Hellriegel expresses a doubt whether it can justly be said that seeds so immature as those of his first two periods are capable of germination; for since the seeds in an ear of grain do not all develop at precisely the same rate, it is possible that a few precocious individuals may have attained a degree of ripeness not really proper to those periods. It is remarkable that even the seeds of the 4th collection did not germinate freely, although they were tolerably hard and dry when taken from the ears. The young plants from the over-ripe seeds were decidedly the strongest and most vigorous, the others being smaller and

feebler very much in proportion as the seeds from which they grew had been gathered earlier.

The results of the trials with seeds sown in the open field were similar to the foregoing; the less ripe the seeds, the fewer of them germinated, and the weaker were the young plants. On the sandy soil, these differences persisted throughout the entire life of the plant, but in the rich garden-soil the weak plants soon grew strong, and were equal to the best before they had ripened. As Hellriegel has shown in other experiments, the hurtful influence of light seeds may speedily be overcome in a fertile soil where all the conditions are favorable for growth, while on poor or dry land a crop may never recover when thus crippled at the start.

B. Of seeds that were left attached to the straw until just before sowing, and so subjected to after-ripening, there germinated,

I.	II.	III.	IV.	V.
77½	77½	78½	88½	88

It is noteworthy what an enormous influence the after-ripening had upon the germination of seeds from the 1st and 2d collections. But it was remarked that as regards the vigor of the young plants the influence of the after-ripening was less pronounced.

C. Of seeds that were left in the ears merely, there germinated,

I.	II.	III.	IV.	V.
81	72	82	84	84½

Even here, where the after-ripening was due merely to matters that could pass out of the chaff into the seeds, the germinative power was enormously increased, though the young plants were very feeble.

D. The seeds left on plants whose roots were put in water germinated as follows: —

I.	II.	III.	IV.	V.
61	62½	87	91	84½

These results were disappointing, because better things had been expected; but in view of the rough manner in which the plants were dug up (with a spade), it is easy to believe that their roots were injured, and that the plants were in no fit condition to nourish their seeds normally.

Rapidity of After-ripening.

The following experiment may serve to illustrate the rapidity with which after-ripening occurs. A quantity of rye was mown before complete ripeness; one quarter of it was deprived at once of its seeds, and the rest kept in a cool, shady place, where the

plants could ripen off without spoiling, or drying too quickly. After 8 days the second quarter was threshed, after 27 days the third quarter, and after 50 days the fourth. One thousand kernels of this rye dried at 212° F. weighed in grams: —

		Gain in Per Cent.
Taken from the ear immediately on harvesting . .	19.890	....
Ditto, after 8 days	22.100	11.1
Ditto, after 27 days	22.240	11.8
Ditto, after 50 days	22.050	10.9

That is to say, 8 days, and to all appearance less, were sufficient to complete the process of after-ripening.

It is evident from Hellriegel's experiments that, for use as seed-grain, dead-ripe seeds must be in all cases the best and the surest, and that, the less ripe the seed, so much the feebler will be its germinative power and the initial productive power of the young plant. Practical illustration of these propositions is given constantly by those over-ripe kernels which shake out upon the fields when grain is harvested. When timely showers occur, such self-planted grain will sometimes germinate and grow with a vigor which is surprising. Practical men agree that, for agricultural crops, ripe sound seeds are needed in order that quick, vigorous germination may be ensured, and that the young plants may get such a grip upon the soil as will enable them to outgrow the assaults of slugs and insects.

Imperfect Seeds are specially ill-adapted for Poor Land.

On poor land, two marked disadvantages, due to imperfect seeds, manifest themselves; viz., fewer plants are developed than there would be by good seed, and these weak plants remain feeble all their lives. Whereas on good soils, as has been said, the chief trouble from poor seed is that comparatively few plants are developed. What plants there are soon overcome their first weakness, and finally attain to a robust development. Thus Hellriegel found, as the average of his four series of experiments, that each single rye-plant grown on sandy loam yielded the following amounts in grams according as the seeds had been collected at the stated periods of development: —

	Grain.	Straw and Chaff.	Total Crop.
No. I.	0.127	0.770	0.897
No. II.	0.445	1.266	1.711
No. III.	1.062	2.697	3.759
No. IV.	1.181	2.886	4.047
No. V.	1.075	2.824	3.899

But when grown in garden-earth each single plant yielded on the average of the four series of experiments: —

No. I.	4.693	9.241	13.934
No. II.	5.116	10.735	15.851
No. III.	5.553	10.553	16.106
No. IV.	5.436	10.926	16.362
No. V.	5.725	11.211	16.936

Crops need to be fed when Young.

There is still another point of view from which to regard the process of ripening. Inasmuch as every plant has to form roots, leaves, and stem before the fruit can appear, i. e. organs which collect and store up the materials from which the fruit is formed, it follows that, in case a plant has not been able to collect a sufficient quantity of these fruit-producing constituents by the time of flowering, it cannot by any possibility bear abundant fruit. Hence the importance of supplying to seed-crops from the first moment of their growth proper quantities of all the kinds of food that are necessary to form grain as well as leaves. Knop's maize-plant, for instance, would not have ripened seed as it did unless it had been well fed when young.

With forage-crops the case is somewhat different. Were it not for the fact that herbage which has grown too rank is apt to be distasteful to animals, and that many kinds of plants which have grown too rapidly are peculiarly liable to lodge, when beaten down by wind or rain, there would be no harm in forcing forage-crops by dressing them frequently with nitrogenous manures. It would be mere folly, however, to attempt to force a grain-crop in this way, unless the young plants had access to an abundance of phosphoric acid, and all the other ash-ingredients necessary for the formation of grain, as well as to nitrogen, and unless the conditions were favorable for the consumption of the ash-ingredients by the plants.

The same reasoning that teaches the necessity of the early harvesting of forage-crops applies of course to green crops that are to be turned under as manure. They should be ploughed under when in flower, or even just before flowering, for at that time they are richest in easily decomposable organic matters, and contain nearly all the ash-ingredients they are capable of taking. It is usually important, moreover, in green-manuring, to save as much time as possible in order to get in another crop, and to avoid the

formation of seeds, whether those of the crop itself or of the weeds that grow with it.

Large Beets and Turnips less Nutritious than Small.

In respect to root-crops, a consideration of general interest is whether large roots or small roots are most nutritious. It was noticed long ago by the German farmers, that, when they manured mangolds with night-soil, they got enormous roots indeed, but very watery roots. Careful experiments have confirmed this observation; so that, as a general rule, it may be said that the larger the root, the larger will be the proportion of water contained in it as compared with the amount of solid matter. But, on the other hand, there can be no doubt that it is good husbandry to grow large roots when possible, since the advantages as regards harvesting, storing, and handling are greatly in their favor.

As for the greater feeding value of small roots, it was noticed at the close of the last century by Young, that in some parts of England the butchers preferred and would give more money for turnips that had never been hoed, and had consequently grown no larger than a double fist, to those which had been cultivated with the greatest care, and were as large as a peck measure. Young ridiculed the idea, and from the farmer's point of view it is absurd; but for the butcher, who buys the turnips by weight, merely as so much cattle-food, and who has no profit in cultivating them, the small ones are doubtless best.

With regard to the comparative power of various crops to exhaust land, enough has been said perhaps already under the head of Rotation.

CHAPTER XXXVI.

BARLEY.

Barley may well be studied as the first example of a special crop, because it is the most widely distributed of the grains. It has been longer cultivated, perhaps, and more generally cultivated, than any other. The growth of the barley-plant has been very carefully investigated, withal, from the scientific point of view. Like the other cereal grains commonly cultivated in temperate climates, barley can begin to grow at very low temperatures. It can germinate, even, at the temperature of melting ice, and will grow when the mean daily temperature is no lower than 41° or 42°

F. In this respect the cereals differ widely from many other crops, which do not begin to vegetate until the temperature of the soil and the air have risen very materially.

Barley grows very far to the north, even in Lapland and Iceland. Good crops are got constantly in some localities as high as latitude 70°, where no autumn-sown grain could survive the extreme cold of the winter. Barley has the great merit that its term of growth is short. And this statement is particularly true of high latitudes, at least as regards sheltered sunny situations not too high above the sea-level. In some Swedish localities the crop is said to ripen sometimes in the course of six weeks, and not infrequently in seven or eight weeks. So, too, in some Norwegian valleys, barley is reaped in favorable years 8 or 9 weeks after the seeds are sown, and it is possible to get two crops in a summer. There is a farm in Thelemarken called Triset, which owes its name to the fact that one year three successive barley-crops were reaped upon it. In those regions the stalks are often seen to grow two or three inches in a day. Even in Ireland an instance is recorded where bread was made from barley six weeks after the seed was sown, and "where two crops of barley have been got from the same land in one year, and the second crop better than the first." (A. Young.) Ordinarily, however, in those parts of the world which produce much barley the term of growth of the crop is some 80 or 90 days, say 13 weeks. Although grown far to the north, barley is not so well able as rye or wheat to live through the winter. Even in New England it is grown as a summer crop, though in countries where the winters are milder varieties of winter barley are sometimes cultivated.

Mention has already been made of the influence of continuous light in hastening the growth of barley in high northern latitudes, and of the remarkable circumstance that the character there impressed upon the crop by its exposure to light through many generations may be retained for a time when the seed is carried to more southern localities. In one experiment, barley that bore ripe grain at Alten (70° N.) 67 days after it was sown, required only 67 days to ripen at Breslau in Germany (51° N.); and an instance is reported where some of the Alten barley sown at Christiania (60° N.) ripened in 55 days, the crop having been somewhat forced, as was supposed, by the warmer climate of Christiania.

Barley has a wide Range.

Barley is still cultivated more frequently in Sweden and Norway than any other grain. As a matter of history, it has been longer cultivated there than any other cereal. It was grown there even earlier than rye. Indeed, the name "corn" has been applied exclusively to barley by the Northmen from very early times.[1] In Iceland, barley was grown from the time the island was colonized, in 870, till the middle of the fourteenth century, or even as late as the year 1400. After that time, however, the Icelanders appear to have imported their supplies of grain, and not to have grown barley in any systematic way; though in the last century efforts were made to have the old custom revived, and again quite recently. In 1883, barley was reaped at Reykjavik, in Iceland, 98 days after the seed was sown. The chief difficulty in these northern countries is from severe night-frosts when the barley-plants are young. Such frosts are often very destructive. It is to be said, however, that there are reasons for believing that the climate of Iceland may be even less clement now than it was formerly. (J. D. Whitney.)

In the year 1891, 2,298,978 acres were devoted to barley in Great Britain and Ireland against 2,392,245 acres of wheat, 4,128,127 acres of oats, and 60,148 acres of rye. In the United States, the census of 1890 records that 3,220,834 acres of barley were grown against 33,579,514 acres of wheat, 28,320,677 acres of oats, 2,171,604 acres of rye, and 72,087,752 acres of Indian corn.

Barley grows far to the south also as well as at the north, and it is much used for feeding horses in some southern countries. Indeed, it habitually yields two crops each year on the same soil in hot climates. In Sicily the barley sown in autumn ripens in May, and that sown in May ripens before the autumn. In temperate climates barley is much less important nowadays even than rye, when considered merely as a bread-crop, but large quantities of it are still grown for the purpose of making beer and malt, and not a little barley is used directly as fodder.

Why Barley is used for Beer.

The reason why barley is used for making beer in preference to

[1] Although the terms *corn* and *grain* may have been at one time synonymous, the word corn is now used in the United States only as an abbreviation of Indian corn, i. e. with us corn means maize. But in North Germany corn means rye, and in Scotland it may mean oats. In England wheat is commonly called corn, though sometimes the term applies to barley also.

the other grains, such as rye, wheat, or maize, is that barley-malt contains a larger proportion of certain unorganized ferments, known by the generic name of "diastase," than malt that has been made from either of the other kinds of grain. In all kinds of starchy seeds the starch is changed to dextrin and sugar at the moment of germination, through the intervention of the ferments above mentioned, which are themselves formed in the earlier stages of germination from a particular albuminoid constituent of the seed, called zymogen.

From germinating barley, in particular, the ferment may be obtained in special abundance, and of peculiar efficiency for changing starch to sugar. It is from barley-malt that diastase may be most readily prepared, and it is because of its being specially abundant in such malt that barley is grown for the making of it. Even in case there were no more than one part of diastase in some five hundred parts of barley-malt, this quantity would still be ample for all practical purposes, since one part of diastase is capable of changing one or two thousand parts of starch to sugar, provided it is made to act at a temperature of 149° to 158° F.

Diastase has been found to exist in numberless seeds, and it evidently plays a very important part in helping to dissolve the contents of seeds, and so supplying food for the growth of the infant plant. Probably it may sometimes serve in mature plants also, as a means of changing starch to sugar. After starch has once been changed to sugar, it is an easy matter to convert the sugar into alcohol by fermenting it with ordinary yeast.

Malting a Process of Germination.

Practically, the process of malting barley, or any other kind of grain, is only an artificial method of germination. The grain is steeped in water to make it soft, then drained and thrown into heaps. After a while these heaps become hot and dry, and in the course of a few days each grain "sprouts," i. e. it throws out rootlets. The heaps are then spread to prevent the grain from becoming too hot, and when the rootlets have grown to a length about equal to that of the grain the progress of the germination is suddenly arrested by drying the grain, either in the air, or, more commonly, in a kiln. After the roots have been rubbed off from the grain thus dried, the latter is called malt. The matter rubbed off is known as malt-sprouts, or malt-combs, and is used for feed-

ing cattle. When malt, or a mixture of malt and fresh grain, is crushed and soaked in warm water for a few hours, the whole of the starch in the mixture changes to sugar and dextrin. The solution of sugar, etc., is separated from the insoluble part of the barley and fermented by means of yeast, as was said, while the insoluble matter, known as brewers' grains, is sold for feeding cows. It contains a considerable proportion of albuminoid matter, as well as woody-fibre, and is a valued fodder. Diastase is not peculiar to barley. It is found in other germinating grains, and small amounts of it have been found even in potatoes. Any kind of grain may be malted in the same way that barley is. But practically barley is found to be better than the other grains for this purpose, and barley-malt is commonly used for preparing other kinds of grain for distillation. Enormous quantities of maize, and rye, and rice, and wheat even, as well as potatoes, and occasionally Jerusalem artichokes, are used every day for making beer and whiskey; but they are, comparatively speaking, seldom malted. Instead of that, the grains or the potatoes are mixed with barley-malt for the so-called mashing process, during which their starch is changed to sugar. Then the sugar is fermented, and, if whiskey is to be made, the fermented liquor is distilled to separate the alcoholic liquid from the refuse slop, which is used as cattle-food.

Barley a Delicate Crop.

Curiously enough, in spite of the fact that barley has so wide a range, and is so hardy that at the extreme north it is grown freely where the soil never melts to a depth greater than a few inches, it is rather a tender plant, both in this country and in England. In the region about Boston, a cold easterly rain-storm descending in the spring upon a barley-field where the young plants are just starting will give the crop a serious check, almost as if the plants had been frozen. Too much rain in northern countries is fatal to it. Thus barley is said to ripen at Alten at 70° north latitude, where there are 21 rainy days during its term of growth, while at Reykinvig at 64° 45′, where there are 51 rainy days, it can no longer be grown. It is said to prefer a warm, dry climate, with occasional light showers. Heavy rains are apt to injure it in all countries, especially when they fall soon after sowing, or while the plants are in blossom or ripening.

It is a peculiarity of the cereal grains — more pronounced per-

haps in the case of barley than in any other, and least conspicuous in respect to oats — that they need an adequate supply of moisture during the first stages of growth, and that subsequently their development is favored by a gradual diminution of moisture, even to the point of absolute dryness when the crop has come to maturity. These conditions obtain naturally in many parts of California where barley and wheat are grown with great success, and they are imitated by means of irrigation in the South of Europe, and doubtless in India also.

In field experiments continued through many years, Lawes and Gilbert noted that "Extremely low produce of barley was obtained with both a great excess and a great deficiency of rain during the months of active vegetation. The bad result with excess of rain was coincident with unusually low or unusually high temperatures; and that with deficiency of rain with high temperatures. The highest amounts of produce were obtained with only moderate amounts of rain during the growing period, provided there were a favorable distribution of it and a favorable adaptation of temperature. Whilst an excess of rain, during the growing months, is adverse to the favorable growth of both wheat and barley, a great deficiency of rain during that period is found to be, as would be anticipated, more adverse to the spring-sown barley than to the winter-sown wheat. . . . The fluctuations in the amount of produce dependent on season, manure, and the continued growth of the crop [year after year], are greater in the case of barley than in that of wheat."

From experiments made at Dahme, in Germany, it appears that, although barley succeeds best when the temperature of the soil is kept at 77° F., while rye does best at 68°, it is none the less true that barley can be grown as far to the north as rye, or even farther, because it grows faster. According to Sachs, the lowest temperature at which barley-plants grow is 41°, and the highest 100° F. According to Gasparin, it begins to grow normally when the mean temperature of the air is as high as 43°.

Best Temperature for growing Barley.

Hellriegel finds by experiment that, when all the other conditions requisite for successful growth have been provided for, a mean daily temperature of 61° F. (as taken in the air and in the shade) is most favorable for the growth of barley, i. e. when the whole term of growth of the crop is considered.[1] During

[1] In respect to wheat, which, like barley, begins to grow when the mean temperature of the air has reached 43°, Boussingault noticed long ago that, on the tropical Andes, it succeeds best at a height of 2,000 or 3,000 metres, where the mean temperature is 59° to 61° F. At lower altitudes, he says, where the mean temperature is 75° F., the cultivation of wheat is generally replaced by that of maize.

the first half of its life, when the leaves and stem are growing, a temperature of 59° is best; while for the second half of the plant's life, when the ears and grain are in process of development, the mean daily temperature had better be 63° or 64°. For growing a perfect crop, the mean temperature at noon should not exceed 70° in the shade during the entire term of growth; nor 68° during the first period of growth; nor 73° during the second period. Temperatures higher than 77° measured in the shade during the period of leaf-development, or than 82° during the period of seed-development, were found to have a decidedly bad influence on the amount of crop produced.

Barley a Fastidious Crop.

It is often said of barley, that few crops are more strongly affected by food. Few crops respond more quickly to a generous diet, or languish more decidedly when food is lacking. Farmers hold that the best soil for barley is a light, rich, friable loam; but that it will do well on clays also, provided they have been thoroughly worked, and made fine and mellow. According to Liebscher, young barley-plants may take up, in the course of the first few weeks of their life, almost one-half of all the plant-food which is needed for the growth of the mature crop.

Practical men are firmly of the opinion that heavy land, which has not been well tilled, is unfit for barley. They maintain that, more than most other crops, barley delights in a free, open soil, that is neither too wet nor too stiff; all of which goes to show that the plant is somewhat delicate or fastidious, as compared with oats or buckwheat, or with maize even, or the other grains. Formerly, it was taught by English writers that barley should be grown in those districts where the soil is light, rather than in regions where the soil is heavy; and it was thought that, although the plant is well suited by calcareous soils, it will not prosper as a rule on clays, nor upon sandy soils. But it has happened in England, as a consequence of the adoption of tile-drainage and steam cultivation, which permit the clays to be worked much better than could be done formerly, and at appropriate seasons withal, that the successful cultivation of barley has been widely extended. Of late years, a great deal of barley of excellent quality has been grown in the clay-land districts of England after wheat. The wheat-stubble is steam-ploughed in the autumn, when dry; and in the early spring, when the land is dry, it is harrowed, or very lightly ploughed, for the reception of the seed.

The preference of barley for loose, free-working loams is in strong contrast with the behavior of wheat, which needs to be sown on firm land in order that it may prosper. Herein apparently lies the explanation of the well-known fact that barley succeeds much better when grown after wheat than wheat does when grown after barley. But in dry climates, care has to be taken, even with barley, that the land shall not be ploughed so deeply and frequently, and at such seasons, that the store of moisture in it shall be dried out unduly.

Manuring of Barley.

It was a maxim of the old English farmers, that there is small use in applying farmyard-manure to a crop which is to remain on the land so short a time as barley does; they argued that the land must be prepared for the barley beforehand by manuring some preceding crop, or by applying manure in the autumn. It is true, withal, that fresh manure is not suitable for barley. On the Continent of Europe it is held that barley on which sheep have been folded is worth but little for brewing beer, but in England, in the light-land districts, barley was formerly grown not infrequently after turnips which had been eaten off by sheep in the fields, the land having been ploughed lightly soon after the sheep were taken off, in order to cover their droppings. Sometimes the barley was sown on this first furrow; but, in case the ploughing were done early in the season, the land was cultivated or harrowed again before seeding, it being considered all important to have a well pulverized seed-bed. This line of argument would lead naturally to the use of quick-acting fertilizers, such, for example, as Peruvian guano, especially that which has been treated with sulphuric acid.

Lawes and Gilbert have said that "Spring-sown barley, which has but a short time in which to extend its roots and to gain command of the resources of the soil, throws out a large amount of root-fibre near the surface, and is more benefited by the application of direct mineral manures, especially by easily assimilable phosphates, than is the autumn-sown wheat, which has 4 or 5 months longer for root-distribution, and is less dependent on the stores of the surface-soil." As a matter of fact, the farmers of the beer region in the North of France — in the vicinity of Lille, for instance — are accustomed to apply liquid manure in the autumn, as a preparation for barley, or, in default of that, to use very well rotted dung.

In general, it may be said that care should be taken not to use such manures, or such quantities of manure, as would tend to make the crop run to leaf rather than to bear seeds. Although barley responds well to proper dressings of assimilable nitrogen compounds, and may be said to require nitrogenous feeding, it cannot, under ordinary circumstances, bear such large amounts of ammonium salts or nitrates as wheat. Lawes and Gilbert have insisted that there is a disadvantage in growing barley after the folding of sheep on turnips, even on light land, in that, with high farming, the land is apt to be left in too high condition, on the average of seasons. On heavier land, so much injury may be done to the texture of the soil by the trampling of the animals that it would be difficult to obtain the fine tilth so essential for the successful growth of barley.

They recommend light dressings of either guano, ammonium sulphate, nitrate of soda, or rape-cake, together with a small quantity of superphosphate, to be applied in the spring to land which has previously borne wheat or a root-crop, and has been enriched for that purpose. Maercker also urged that nitrogenous manures must be used with care, lest the quality of the crop should be injured, from the brewer's point of view. Moderate dressings of nitrate of soda, or of sulphate of ammonia at equal price, are not dangerous; though it is better to use neither. It is to be borne in mind always that barley is a short-lived plant; its roots grow rapidly, they are feeble and ill-adapted to surmount obstacles such as are presented by a compact soil, or to utilize fertilizing matters which are not ready and waiting to be taken in.

Experiments by Lawes and Gilbert which exhibit the importance of assimilable nitrogenous fertilizers for the barley-crop will be described directly. It is said that in some parts of England barley is often grown immediately after wheat, even in a four-course rotation, because, on land where barley is apt to become coarse, grain of better quality can be got after the wheat-crop has been made to reduce, in some measure, the too great richness of the soil.

Voelcker remarked some years ago that neither ammoniacal manures nor nitrate of soda gave satisfactory economical results in his field experiments on barley, while superphosphate often did much good when the barley had been sown late. He urged also that it is more dangerous to sow barley very late on soils that

have been highly manured with nitrogenized animal fertilizers than on poor land, for on such rich land late-sown barley might not get ripe enough to be of any use for malting. In some parts of Germany, where large quantities of barley are grown in conjunction with sugar-beets, two crops of barley are often taken after one of beets. It is said that even the second barley-crop usually succeeds well, and that the grain is of excellent quality and appearance. On the heavy English soils just now mentioned, the barley is dressed liberally with artificial fertilizers, viz. with 2 or 3 cwt. of superphosphate applied before seeding, and from 0.5 to 1 cwt. of nitrate of soda.

Some of the experiments of Lawes and Gilbert bear upon this point. For many years these investigators have continually grown crops of barley (as well as of wheat) upon the same fields, and some of their results are set forth in the following table. The soil of their fields is "a somewhat heavy loam, with a subsoil of raw, yellowish red clay, but resting in its turn upon chalk, which provides good natural drainage." The crops harvested were as follows: —

Manure to the Acre.	1st Year. Grain. bush.	1st Year. Straw. cwt.	20th Year. Grain. bush.	20th Year. Straw. cwt.	Average of 20 Years. Grain. bush.	Average of 20 Years. Straw. cwt.
14 tons of farmyard-manure	33	18½	54¼	37⅛	48¼	28½
No manure	27¼	16⅝	16¾	11	20	11¾
Mixed minerals[1] . . .	32¾	19½	25	14	27½	14⅝
200 lb. ammonium salts[2]	36⅛	22⅞	36⅝	23⅛	32½	18½
Mixed minerals and 200 lb. ammonium salts .	40¾	27⅞	46½	32⅛	46¼	28½
Minerals and 400 lb. ammonium salts[3] . . .	45⅛	28⅝	46	32⅝	49¾	32⅝
Minerals and 2,000 lb. rape-cake[4]	38	24⅛	47½	32	47⅝	29½

In order to contrast the action of ammonium salts with that of nitrate of soda, 200 lb. of the former and 275 lb. of the latter, estimated to contain respectively 41 lb. of nitrogen, were applied year after year for 20 years, in the one case, and 19 years in the

[1] The mixed minerals consisted per acre and per annum of 300 lb. of sulphate of potash during the first 6 years, and 200 lb. thereafter; 200 lb. of sulphate of soda during the first 6 years, and 100 lb. afterwards; 100 lb. of sulphate of magnesia; and 200 lb. of bone-ash treated with 150 lb. of sulphuric acid of 1.7 sp. gr.

[2] The ammonium salts consisted of an equal mixture of the sulphate and the chloride.

[3] After the 6th year, and during the next 10 years, 200 lb. of the ammonium salts; and subsequently 275 lb. of nitrate of soda were used.

[4] After the 6th year, 1,000 lb. of rape-cake were used each year, instead of 2,000.

other. But it is to be noticed that a shade of doubt is thrown upon the results obtained, because in the first year of the experiment the plot subsequently devoted to nitrate of soda was dressed with a mixture of superphosphate and sulphate of potash, and this reinforcement doubtless had a considerable influence in helping the nitrate to give better crops than were got from the plain ammonia plot which received no addition of mineral fertilizers. For the sake of clearness, the results of these special trials are given in a separate table, though they properly belong to the preceding table, and are strictly comparable with the results there given: —

Manure to the Acre.	1st 10 Years. Grain. bush.	1st 10 Years. Straw. cwt.	2d 10 Years. Grain. bush.	2d 10 Years. Straw. cwt.	Average of 20 Years. Grain. bush.	Average of 20 Years. Straw. cwt.
275 lb. nitrate of soda, 19 years	37.6	23.4	37.1	22.5	37.4	22.9
200 lb. ammonia salts, 20 years	33.6	19.4	31.4	17.4	32.5	18.5
550 lb. nitrate of soda, 5 years	. . .	. . .	. . .	. . .	48 (5 yrs.)	31.5
400 lb. ammonia salts, 6 years	. . .	. . .	. . .	. . .	46	28.5

These large, double dressings of active nitrogenous fertilizers were found to be too heavy. The crops grown upon land thus dressed were frequently much laid. Hence, after the 6th year of the experiments, the quantities were reduced one-half, and the crops obtained were compared with those from plots, as stated in the table, which had received from the beginning 200 lb. of ammonium salts, or 275 lb. of nitrate of soda. It was noticed that for many subsequent years the plots which had at first received the larger amounts of nitrogen, either alone or admixed with mineral fertilizers, continued to yield more produce than the plots which had received the smaller amounts of nitrogen from the beginning.

It appeared from these experiments, very much as had been the case with wheat, that on a moderately fertile soil it was not possible to grow good crops of barley by means of mineral manures (ash-ingredients) alone; that fairly good crops could be got during 20 successive years by means of small dressings of active nitrogenous fertilizers, and that excellent crops could be got year after year by applying mixtures of nitrogenous manures and superphosphate.

Much more than the average barley-crop of the locality was obtained for 20 years in succession by the annual application in the spring of 200 lb. of ammonium salts and 3.5 cwt. of superphosphate of lime; but no further increase was obtained by the addition of salts of potash, soda and magnesia.

The average annual yield during the 20 years was, with ammonium salts and superphosphate, 47.1 bushels of dressed barley, and 27.6 cwt. of straw; with the same amount of ammonia and a mixture of the sulphates of potash, soda and magnesia it was 35.1 bush. and 20.75 cwt.; and with a mixture of ammonia, phosphate and minerals, it was 46.4 bush. and 28.5 cwt.

Over the whole period of 20 years, the average annual increase due to the continued action of ammonia and superphosphate was 26.1 bush. and 15.5 cwt., and that due to ammonia, superphosphate and the other minerals, was 25.4 bush. and 16.4 cwt., while the increase due to ammonia and the saline minerals (without superphosphate) was only 14.1 bush. and 8.6 cwt. The crops obtained by using the mixed nitrogenous and phosphatic fertilizers were rather larger than those got by means of farmyard-manure, and the grain was heavy.

Gain of Barley per lb. of Nitrogen applied.

As with wheat, so with barley; Lawes and Gilbert have tried to express in numbers the effect which is produced by active nitrogenous fertilizers when applied to barley-crops. They conclude that when barley, grown after dunged roots which have been removed from the land, or after wheat, is manured with from 1.5 to 2 cwt. of sulphate of ammonia, or 1.75 to 2.25 cwt. of nitrate of soda with 2 or 3 cwt. of superphosphate per acre, — or with 3 to 4 cwt. of guano containing 12 % of ammonia, without superphosphate, — an increase of 1 bushel of grain (52 lb.), and its proportion of straw (say 68 lb.), may on the average of seasons be counted upon for every 1.65 to 1.86 lb. of nitrogen or its equivalent of ammonia (2 to 2.25 lb.) supplied in the manure.

It was observed, however, that there were wide variations in the amount of nitrogen required to yield a given quantity of increase according to the season, to the amount applied, and to the previous condition of the soil. It was essential, in any event, that no excessively large quantity of nitrogen should be applied, and that there should be no deficiency of mineral constituents in the soil. The above prediction applies only to the nitrogen of nitrates, ammonium salts and Peruvian guano. As regards farmyard-manure and sheepfold, it appeared that much less increase of barley was yielded in the year of the application, in proportion to the nitrogen contained in the manure. With rape-cake, also, rather more nitrogen than the amounts above specified was required to obtain the given increase of crop.

It appeared that barley put the active nitrogen to rather better profit than wheat did, for while 100 lb. increase of total produce of wheat were got by using 3 lb. of ammonia, no more than 1.75 to 2 lb. of ammonia were required to produce 100 lb. of increase of barley. That is to say, the spring-crop barley required less ammonia to yield a given amount of increase than the autumn-sown wheat. It is to be understood, however, that a good soil is needed for continuous barley-growing. It is a tenet of practical agriculture that, while several successive crops of oats may be taken with profit, barley would usually give very indifferent crops under similar circumstances. It is said, moreover, that barley will do better when grown after oats than it will when grown after barley.

A curious example of the influence of manure upon the quality of the barley-crop has been described in the following terms: "It is greatly in favor of French barley [as compared with English], that it is never grown on land upon which roots have been fed off by sheep, which always affects its color. The brightest and best samples in England always come from land the previous crop on which has been wheat; but this system of farming is far from general, most of the barley being from land on which turnips have been fed off by sheep. In France a highly manured beet-crop, followed by wheat, and that again followed by barley — both the grain-crops being taken without manure — will give the best and finest barley produce." (Richardson.) It has been urged that, since a crop of winter wheat occupies the soil four months longer than a barley-crop, it can take more out of the land than either barley or oats, and consequently requires either a better soil or larger applications of plant-food. (Caird.)

Dead-ripe Barley best for Malting.

It is said that when barley is to be used for making beer it must not be harvested before it is dead ripe. The rule is to wait until the ears droop, and have lost their reddish color. The argument in this case is, that, for the success of the malting process, it is important to have the grain all of one stage of ripeness, so that it shall germinate simultaneously; and, in order to this result, each and every kernel of the grain must be perfectly ripe. But when grown for use on the farm, it may be said of barley, even more strongly, perhaps, than of other grains, that it should be cut down while the seed is still not very hard, and the straw not ab-

solutely dry. The sheaves are then left for some time in the field, in order that the grain may finish taking nutriment out of the straw, and so ripen; for if the crop is left standing too long, much grain will inevitably shake out from the ears and be lost during the process of reaping. On the other hand, if sheaves of barley, or of any other grain, were to be housed, or put in a stack, immediately after reaping, fermentation and decay would set in, the process of after-ripening would be interrupted, and the crop be spoiled.

Pasturing of Grain-Plants.

In some countries it was customary formerly to mow barley in the spring in case it threatened to be over-luxuriant, or to have it eaten down by sheep. In this way animals may be supplied with very nutritious fodder, while the risk of the crop's becoming lodged is greatly diminished. Mowing was esteemed to be better than pasturing, since it was easy to cut off only the rankest plants with the scythe, and so to bring the crop to a condition of comparative evenness. So, too, in autumn, excellent forage for soiling cattle can be got by sowing fresh barley, such as rattles out from the sheaves immediately after they have been harvested.

The custom of mowing a crop in the spring in case it threatened to be too rank, or of having it eaten off by sheep, applied not only to barley, but to the other kinds of grain, and especially to winter grain. Pasturing was thought well of when applied to winter rye in the autumn, whereby many young weeds were eaten off, and in the winter also, when the crop was frozen dry, but in the spring it was objectionable, because it is to be feared that the sheep might suffer from hoove on eating greedily of the young, succulent grain-plants. To avoid this danger the animals were usually driven so rapidly across the field that the clipping of the plants was very imperfect, and the crop was apt to be left in a ragged, uneven condition.

As regards wheat, spring pasturing was often condemned because the rank young shoots were thought to be specially dangerous food for sheep, and because the crop itself was apt to fail when thus eaten off. But in some districts the practice was well-nigh universal whenever the spring happened to be backward, and the store of winter forage had been expended. Marshall tells of journeying, in May, in the eastern part of Norfolk County, when "The wheat appeared to be almost universally pastured by stock of every denomination excepting sheep (which were rarely kept in that district); but calves, young stock, cows, and even fat bul-

locks and horses, were still to be seen in almost every close of wheat we passed. The spring of this year, however, is remarkably late; the turnips are gone, and the grass not yet come to a bite."

Hellriegel's Perfect Barley-Plants.

A great number of highly interesting experiments on the growth of barley[1] have been made by Hellriegel at Dahme, in Germany. He propounded to himself squarely the question, How much barley could be grown on an acre of land provided all the conditions were the most favorable that can be conceived? That is to say, what would be, theoretically speaking, the maximum harvest? As conditions essential to perfection Hellriegel admits that the plants must have a certain volume of porous soil, which shall afford the necessary space for the development of the roots, a sufficient supply of moisture, definite quantities of assimilable food, both in the air and in the soil, as well as specific amounts of light, heat, and time. Strictly speaking, each one of these conditions is as important as any other. Either of them may exert a decisive influence upon the quantity of the crop; and it is only when each and all of the conditions are present in proper quantity or force, i. e. when they make themselves felt in just proportion, that the best possible or really normal plant can be obtained.

It will be seen at once that, though theoretically of equal weight, some of these conditions are practically much more easily controlled than others. It is a comparatively easy matter, for example, to supply in field practice as much phosphoric acid, nitrogen, or potash as may be needed by a maximum crop, though in many instances it would be very difficult to provide enough water for the purpose. Over heat and light, moreover, the farmer has little or no control.

Hellriegel assumed that, when all the conditions necessary for a perfect crop have been found out, it will be possible to alter the character of the crop at will, or the quantity of the crop, by changing certain of the conditions. Acting on these ideas, he has succeeded in growing perfectly healthy plants, much larger and better than are ever found in the fields; and, within certain limits, he has been able to control pretty much as he saw fit the influences exerted by light, heat, food, and the other conditions which are necessary to the life of plants. That is to say, by varying the

[1] The small four-rowed variety (Hordeum vulgare).

conditions, he was able to produce at will plants of determined size and weight, and to obtain constantly the same results under like conditions.

But this term "like conditions" requires for its fulfilment that the seed-grains shall be of identically the same absolute weight, and of like specific gravity; that they shall be buried to an equal depth, at one and the same time; that they shall have equal quantities of earth, and that the pots shall be placed in common relations with sun and air; that each pot shall be kept equally moist with the rest, and receive the same amount of food, and the same protection from all disturbing influences.

If either food or moisture be lacking, the starveling plant will speedily come to maturity; the stalk will grow to a height of 2 or 3 inches, an imperfect ear will form upon it, and this ear will quickly ripen. In case the plant is partially fed, its growth will be correspondingly incomplete. Similar appearances are constantly seen, for that matter, in field practice, as when grain grown on dry, sterile land ripens prematurely, and yields a light crop, while that standing in a rich, moist soil stools freely, and grows to a large size, and finally ripens off slowly, and produces heavy grain. It is noticed, too, in field practice, that an excess either of food or moisture may be harmful, in that the leafy parts of the plants are apt to grow too large, and to continue to grow so late in the season, that the process of ripening and the production of grain is interfered with.

Needs of the Perfect Plant.

In order to control the matters of light and air, Hellriegel had the pots set upon a sort of wagon, running on a railway, which could be drawn out of or into a glass house at will, according as the weather required. Most of these experiments, which were continued for many years, were made in large glass jars filled with pure quartz sand, to which the necessary nourishment was applied in the form of soluble chemical substances. For example, in order to answer the question, What chemical substances, and what quantity of each, must be present in the soil or the air in order to support the largest possible crop of barley? several distinct series of trials were established by mixing with the sand chemical substances in different proportions, and in each of these series one of the essential elements of plant-food was supplied at ten or twelve different rates, ranging from nothing (i. e. 0) at one end

of the series up to a very large quantity at the other end, — a quantity so large, namely, that it would surely be in excess of what the plant needed. Thus, in seeking to determine how much potash is required by the barley-plant in order that it may be perfect, when the other conditions necessary to the prosperity of the plant are fulfilled, Hellriegel obtained the results given in the following table: —

No. of Pot.	Lb. Potash in a Million lb. of Earth.	Weights of Crops harvested.		
		Straw and Chaff.	Grain.	Total.
1	0	0.798	. . .	0.798
2	6	3.869	2.933	6.802
3	12	5.740	4.695	10.435
4	24	6.859	7.851	14.710
5	47	8.195	9.578	17.773
6	71	9.327	10.097	19.424
7	94	8.693	9.083	17.776
8	141	8.764	8.529	17.293
9	282	8.916	8.962	17.878

Each of the pots was abundantly supplied with lime, magnesia, soda, iron, silica, nitric acid, sulphuric acid, phosphoric acid, and chlorine; and the results seem to show that between fifty and seventy pounds of potash to a million pounds of earth are necessary for the perfect barley-crop. But from analyses of the ashes of the crops obtained as above, Hellriegel concluded that 47 lb. of potash to the million pounds of earth are sufficient, or rather that the necessary quantity lies somewhere between 24 and 47. The reasons for this opinion will appear from the following table, which gives the per cents of potash in the dry crop. There were found the following numbers of pounds of potash in 100 pounds of the dry crop: —

No. of Pot.	Straw and Chaff.	Grain.
2	0.459	0.175
3	0.371	0.181
4	0.425	0.354
5	0.990	0.375
6	1.791	Lost.
7	2.680	0.497
8	4.068	Lost.
9	6.428	0.669

The proportion of potash in the grain, it will be observed, remains tolerably constant after No. 4. In case the soil contained an excess of potash, some of it did, indeed, accumulate in the straw, but it did not increase the yield of grain, nor did the grain

willingly take in any excess of potash over and above what may be called the necessary quantity.

Even if nothing were known as to the function of potash in the economy of the plant, it would still be manifest, from the results of these experiments, that potash has some definite work to perform, and that there is no use in sending two pounds of it to do one pound's work. Hellriegel concludes that, for the production of every 1,000 lb. of dry straw and chaff, the barley-plant must have at the very least (taking the results of Pot No. 4) 5 lb. of potash, and for every 1,000 lb. of grain 3.8 lb. of potash.

Crudeness of Field Practice.

It will be interesting to compare the foregoing ideal with the results of ordinary farm practice, and to observe how far removed we still are from perfection. If it be assumed that the average yield of barley in Massachusetts is 25 bushels to the acre, and that a bushel of this grain weighs 48 lb., there would be 1,200 lb. of grain, needing 4½ lb. of potash; and if the straw of the Massachusetts crop weighed 2,400 lb. to the acre, that would need 12 lb. of potash, or altogether the crop would need 16½ lb. But actually and practically no one would deem it amiss to apply 100 lb. of potash to the acre of land. Eight cords of cow-manure might contain more than 200 lb. of potash. This calculation, taken in connection with the fact that the small proportion of potash above mentioned is sufficient to produce a larger crop than was ever harvested in field practice, teaches an emphatic lesson with regard to the manuring of land. It teaches that efforts should be directed towards bringing the soil into fit conditions as regards moisture, and supplying crops with adequate quantities of soluble, diffusible, and easily assimilable fertilizers, instead of heaping upon it great masses of comparatively inert materials.

In the jars of soil which contained less potash than was required by the maximum crop, Hellriegel observed that the plants were less and less luxuriant, and finally short and stunted. The diminution in size was visibly nearly proportionate to the lack of potash.

Experiments made in the same way with varying quantities of phosphoric acid, or lime, or magnesia, gave results which were strictly comparable with those obtained with potash. And, as has been said already, it was proved by means of analogous experiments that the carbonic acid of the air is sufficient for the produc-

tion of a maximum crop of barley. There was no advantage gained on giving the plants more carbonic acid than the air naturally afforded them.

In the same way, it was proved that the ammonia and nitrates of the air are wholly insufficient for the growth of even a tolerable crop. Thus, in pots that contained all the ash-ingredients in abundance, but no nitrogen, the harvest was 0.184 grm. of straw on watering with distilled water, and 0.200 grm. on watering with rain-water, while in similar soil to which a nitrogenous fertilizer was added at the rate of 84 lb. nitrogen to the million pounds of earth, the harvest was: —

Grain.	Straw and Chaff.	Total.
9.083	8.693	17.776

Importance of Light for Growth.

The influence of different-amounts of light was tested by growing some crops of barley in free air, while others were grown at the front and at the back of a glass house. Only the crop grown in free air was perfect. That at the front of the house was below par, and the one from the back of the house, where there was no direct sunlight, but only diffused light, was very poor. The dry weight of the three crops was as 7 : 3 : 1 (very nearly). All the conditions other than the amount of light being at their best, the harvests were as follows: —

	Ears.	Barren Stalks.	No. of Seeds.	Weight of Dry Matter in Milligrams. Grain.	Straw and Chaff.	Total Crop.
A. Barley grown in free outer air: —						
	17	10	285	10,102	11,436	21,538
	12	8	312	11,188	10,991	22,179
Mean,	15	9	299	10,645	11,214	21,859
B. Grown in front part of glass house in direct light: —						
	11	4	123	2,861	6,716	9,577
	11	3	143	3,265	6,323	9,588
Mean,	11	4	133	3,063	6,520	9,583
C.[1] Grown at back of glass house in diffused light: —						
	0	16	0	. . .	3,396	3,396
	0	20	0	. . .	2,594	2,594
Mean,	0	18	0	. . .	2,995	2,995

So, too, when the plants were somewhat shaded by being covered with glass that was slightly colored, or when they were partially screened with paper shades which cut off daily most of the light

[1] The plants in C were spindling, thin, and soft.

from the lower portions of their stems, the amount of crop harvested was invariably lessened.

These experiments forcibly illustrate the sacrifices in respect to light which gardeners are compelled to put up with in their hot-beds and greenhouses for the sake of getting and preserving heat in the winter and the spring. It is well known, for that matter, that even thin panes of glass may cut off ten per cent of the light which falls upon them from a candle or a gas-lamp, i. e. under conditions which might be supposed to be particularly favorable for transmission, while the loss of light from thick glass and from that which is colored may amount to very much more than 10 per cent.

Hellriegel calls attention to the fact, that the plants in the midst of a grain-field are much less favorably situated as regards light than were the plants of his normal experiments. Each of his plants had constant access to all the light that shone during the entire term of their growth. But in the field the plants are necessarily a good deal shaded by their fellows, except in earliest youth when they are not large enough to interfere with one another, and in maturest age when their leaves have perished. He urges that this point has important bearings upon a number of practical questions, such as, How thick should a grain-crop stand? How thickly should meslin be sown? How wide should the distance between the drills be made in sowing one or another crop? and, In what directions should the rows of plants be made to run? For the amount of light which falls upon a field, and the best possible utilization of this light are prime factors for the success of a crop.

According to Koch, even the "lodging" of grain may depend largely on a lack of light. When grain-plants are very much crowded, not enough light can come to them to ensure their proper development. But when grain has been sown thinly, the plants usually stand up firmly enough. Where heavy crops of grain are to be grown, it is well to sow the seed in drills as a means of hindering the tendency to lodge; for plants standing in rows will naturally be more strongly illuminated than those springing from seed which has been sown broadcast.

American experience in growing fodder-corn (maize) for ensilage has shown very clearly that the corn should not be sown broadcast, but in drills, and not too thickly. In order to obtain a

heavy, well-conditioned crop, it is important that each corn-plant shall have elbow-room and abundant sunlight. In default of light, as when the crop is crowded, the plants remain limp and immature, and no such abundant production of starch and sugar is obtained as on fields where the corn has been sown less thickly. Formerly it was customary to sow rather thickly corn-fodder that was grown to be fed out green to cows, from day to day, to supplement the grass of their pastures in times of drought; and the practice may perhaps be defensible on the grounds that such corn-stalks are cut in midsummer, long before the plants can have reached maturity, and that, in the absence of abundant light, the stalks remain soft and tender, and do not grow firm and hard.

It is a matter of practical experience both with flax and hemp that the seeds should be sown thickly when a fine fibre is sought for, but somewhat thinly when the object is to get a good yield of seeds. In view of the evidence here presented, there can hardly be a doubt that some part of the detestation in which weeds, as well as trees, growing among crops, are held by practical men, must be credited to the shade they cast.

Weeds may shade some young Plants.

It is noticeable that farmers take special care to clear the land for and to weed those crops — such as flax, onions and carrots — which do not quickly rise to any great height above the surface of the ground; and it is evident that these plants suffer severely, especially when young, in case they are neglected to such an extent that their leaves become overshadowed by tall weeds. But for taller plants, such as hemp and maize, or even potatoes, hand-weeding may often be dispensed with, and the horse-hoe alone be used, because tall plants when well "cultivated" rise above most of the weeds which have escaped destruction, and thus gain access to sunlight. Hops also, when once well started, suffer less than many other plants from weeds that are left to grow among them. Crops which, like peas and dandelions, grow freely in the cool weather of early spring, are specially esteemed for cleansing land. As everyone knows, early-sown peas will grow large enough to cast a dense shade before hot-weather weeds have started, and the crops which succeed peas find a clean and mellow soil. In this sense dandelions are sometimes grown before strawberries as a means of checking weeds.

It needs to be said, however, of carrots, that in the garden-cul-

ture of Belgium they are often sown together with flax, or with wheat or rye; in Germany they were sometimes sown with rape. The explanation of this custom is that the carrots, after having struck root, simply wait — i. e. they grow with extreme slowness — until the removal of the other crop, when they take on a new lease of life and continue to grow vigorously during late summer and the long warm autumn of the locality. In case flax and carrots are sown together in March, the flax is pulled up by July 1st, and the carrots are pulled in their turn when the ground begins to freeze. The yield of roots is stated as 10 tons to the acre.

In like manner, when carrots have been sown with wheat or with rye, the grain-crop is harvested in due course by pulling the straw up by the roots. Thenceforth the carrots grow in clean land free from shade, and yield on the average some 8 tons of roots to the acre. In consonance with the old practice of sowing carrots with grain or flax, it is customary in some localities, even when carrot-seed is sown by itself, not to hasten unduly with regard to the first weeding of the young plants. Not only is it difficult to distinguish very young carrots from young weeds, but experience teaches that the weeds do the carrots comparatively little harm at first. It is only when the weeds have become large enough to shade the crop, and to steal water from it, that they are seriously hurtful.

More than a century ago Marshall called attention to the fact that weeds may injure some crops by hindering the fertilization of their blossoms. In his own words, "Weeds injure horse-beans, and all pulse, in a way in which they have it not in their power to hurt grain. Grain-plants bear their seeds on the summit of the stem. The weeds must be aspiring indeed if grain cannot blossom in defiance of them. . . . Beans, on the contrary, throw out their seeds from the sides of the stems, down to within a few inches of the ground; provided they have room, air, and sun enough to encourage them to throw out blossoms, and to enable them to bring the pods to due perfection; and it is observable that a crop of beans seldom turns out productive unless the pods are formed low on the stems. Hence the utility of the first hoeing, to prevent the weeds from crowding the beans . . . and to give the beans an opportunity of blowing, as well as of maturing their pods, without the interference of weeds. Hence, likewise, the unproductiveness of a thick-standing, rank crop, which, by drawing up the in-

dividuals tall and slender, forms a shade below, and prevents a due circulation of air."

On the other hand, it is not impossible that the unlikeness of the two kinds of plants in a crop of meslin may hinder them from interfering with one another to the same extent as might be the case if either one of the plants stood by itself as thickly. It is important none the less, as has always been recognized by practical men, that grain should be sown thickly enough that the growing crop shall smother many kinds of weeds which would otherwise befoul the land.

It is to be observed, however, that while it is of the utmost importance that the plant itself shall be well lighted and aired, the soil in which the plant stands had better be kept in shade. A well shaded soil will be less apt to dry out at the surface than a bare soil would be, and it will often be better fitted for the residence of the nitrifying ferments and other useful organisms which love moisture and darkness.

Plants need much Water.

Curiously enough, it was shown, not only for barley, but for wheat, oats, and rye also, that the amount of water which naturally falls at Dahme in the form of rain and dew and snow is insufficient for the production of maximum crops, even if it be supposed that this water could all be stored until it was needed, and then be distributed evenly and in the most advantageous way during the growing season.

Experiments upon the importance of water were made in a sand which was capable of holding 25% of water. It appeared that the barley-plants could not grow, no matter how well they were supplied with other kinds of food, unless there was present in the soil from 3 to 5% of water. When the soil contained no more water than 2½%, i. e. no more than would amount to 10% of all the water it could hold in its pores, germinated seeds would not grow at all, though in point of fact they remained alive during six weeks, and then grew well enough on being watered. It was only when the proportion of water in the sand fell below 2.5% that the plants wilted; but in order that they should grow, more than 5% of water was necessary. It will be noticed that the influence exerted by these small quantities of water bears directly on the significance, for some kinds of soils, of the mere hygroscopic moisture which such soils can absorb from the ground-air, as has been observed in California by Hilgard. (See Chapter IV.)

When water was supplied by Hellriegel in quantities ranging from 5 to 20% of the soil, or in other words from 10 to 80% of the maximum quantity which could be held by the sand, it soon appeared that the size of the plants was very nearly proportional to the amount of water they received, and as time went on the difference between the well watered and the thirsty plants became more and more clearly marked. These results consist perfectly with the experience of market-gardeners in the vicinity of Boston, who are accustomed to grow superb crops on low-lying soils highly charged with moisture. So, too, on the polders of Holland, the draining-ditches are so mananged that the crops shall have access to an abundance of moisture. In New England, also, it is a common practice, during the summer months, to dam the ditches of reclaimed meadows so that a great store of water may be held back in the land for the use of the grass.

In Hellriegel's experiments, where there was no more water than amounted to 20% of the sand's capacity, the young plants were so backward in starting that they were from 2 to 5 days later than those which got an abundance of water, and it was evident that the plants were inadequately supplied with moisture when no larger quantities of water were given to them than amounted to from 10 to 20% of what the sand could hold. In times of specially hot weather, moreover, all the plants that had less water than amounted to 20% of the soil's capacity suffered extremely.

As will be seen from the table which follows, the best results were obtained when the soil was kept pretty thoroughly moistened, but not actually saturated with water. The best results were obtained when 50 or 60% of water were present, while 80%, or more than 80%, of what the soil could hold was detrimental; probably because the excess of water excluded air from the plant-roots, and because the micro-organisms proper to a well-constituted soil were drowned out by it. It is notorious, for that matter, that plants may readily be watered too freely, in which event they are apt to grow soft and flabby, and are not much disposed to produce flower or fruit. When fruit is produced by such plants, it is often well-nigh tasteless. (Gasparin.)

Watered Fruit is often Insipid.

This fact has been borne in upon the American public only too forcibly, of late years, since the markets have been glutted with Californian fruit, produced by trees that have been too freely ir-

rigated. In this sense, Arthur Young remarked, long ago, of Ireland, "Nor do I think that garden vegetables have the flavor found in those of England, certainly owing to the climate; green peas I found everywhere perfectly insipid, and lettuce, etc., not good." In damp, cloudy countries plants are apt to have particularly large leaves, while the spaces on the stems between the nodes or joints are commonly very long. Such conditions are, of course, favorable for pasturage rather than for grain-growing or the production of any kind of seeds. (Gasparin.) In the Southern States of this country, on wet soils and in wet seasons, the yield of cotton is apt to be small, because the plants then take on a large and rank growth. Tobacco plants, also, under these conditions, grow large and rank, and their leaves are coarse and sappy, but they do not cure well or take on a good color.

In Hellriegel's experiments it was noticed that the well watered plants were not only larger than the others, and of a bright green color, but that they seemed as if built upon a larger scale, with larger and thicker leaves and branches. As for the color of the plants which were inadequately watered, though they were provided with all other essential requirements, it was a deep sap-green, similar to that shown by plants that have been fed with an excess of nitrogen; but the general appearance of the plants was, comparatively speaking, stiff and contracted, and it was evident that plants which are forced to grow in a soil that contains constantly less water than the plants would like, may adapt themselves, in a measure, to the situation; their organs become contracted, and their transpiratory surfaces circumscribed. It is to be supposed also, that, whenever there is a lack of moisture in the soil, the contents of the cells are less fluid and less inclined to give up water for transpiration.

It was found, on microscopic examination, that the well watered plants did actually contain more cells and larger cells, as well as more and larger breathing-pores (stomata) than the plants which were less thoroughly watered.

In the experiments recorded in the table, each jar contained 4 kilos of sand and 6 or 7 barley-plants, which were supplied with all the food they needed. The amounts of water were so regulated that each jar received continually a certain definite proportion of it: —

When the Soil contained Water amounting to Per Cent of all it could hold,	The Plants bore Seeds to the number of	There were harvested Milligrams of Dry Crop,
80	276	19,693
60	311	22,763
40	313	21,760
30	269	19,765
20	224	14,620
10	32	3,009
5	...	123[1]

Analogous results were obtained when barley was grown in jars filled with garden-earth, and Hellriegel expresses his conviction that, for the generality of circumstances, an amount of water equal to about half the quantity the soil can hold will be most advantageous on the whole. For experiments which are to be made by the method of sand-culture, he allows that the moisture may range between 60 and 40 %, or even between 70 and 30 %, without injury to the crops.

Watering of Plants in Greenhouses.

The foregoing results are manifestly analogous to those obtained every day by greenhouse gardeners who are familiar with the fact that the development of almost any plant, growing in ordinary loam and subjected to a high temperature, can be controlled in great measure by the amount of watering. When abundantly watered, some kinds of plants may be made to take on a great development of foliage, with but slight tendency to flowering, while by keeping the soil rather dry the plant may be made to bloom the sooner.

It is to be presumed that, inasmuch as rain and dew must often do good by washing away dust from the leaves of plants, and exudations also which have "sweat out" from within the plant, the sprinkling of plants will be much more important in greenhouses than out of doors, where the plants are occasionally washed clean by showers of rain.

Even short Droughts do Harm.

The foregoing statements of Hellriegel relate to experiments where the plants either had or had not water enough for their requirements from the beginning to the end of their lives. But many other experiments were tried, in which the plants were subjected to periods of thirst during one or another term of their development. From these trials it appeared that, as a general rule,

[1] The plants formed three or four leaves, but no stem.

the yield of the barley-crop was very much lessened even by short terms of drought, and that, no matter how copious the subsequent supply of water might be, the plants never recovered completely from the injury they had received. It seemed, moreover, as if the plants which had been particularly favored as to their supply of water suffered more from drought when it came to them than those which had always had to put up with a somewhat inadequate supply of moisture.

Experiments by Schultz, on the use of nitrate of soda in a region of cold, dry, sandy soils, bear upon this point. He found that the nitrate applied to rye or oats, early in the spring, had an immediate and energetic action upon the growth of the young plants, but that the action was ephemeral. It often ceased in the course of a month, and the crops were left in a sickly condition, because plants made succulent by the nitrate cannot so well support drought as plants which have never been richly fed. He found, in general, on this poor, sandy soil, that crops fertilized with kainit and plain superphosphate withstood long-continued drought better than those fertilized with the phosphate and nitrate of soda or sulphate of ammonia.

It was noticed constantly by Hellriegel that periods of drought did more harm in proportion as they fell upon younger plants, and that those parts of the plants suffered most which happened to be in process of formation at the time when the drought set in. It is only when the barley-plant has once happily reached the point at which seeds begin to form in the young ears, that the success of the crop is assured. Thereafter the plants feel drought but little, and the process of ripening off can be finished very satisfactorily, even when the supply of water is small; that is to say, a very moderate amount of moisture in the soil is sufficient to provide for the translocation into the seeds of the ripening barley-plant of the matters which had previously been stored in the leaves and stem and husks.

Relations between the Rainfall and the Amount of the Barley-Crop.

In the light of the foregoing results, Hellriegel has discussed anew the old question whether the rain that falls on a field during the term of growth of a crop can yield a sufficient amount of water for the proper support of that crop. He admits that an average crop of four-rowed barley in the vicinity of Dahme is about 23 bushels to the English acre, or, more precisely, 1,280

kilos of grain and 1,800 kilos of straw to the hectare; whence he computes that 3,300 kilos of dry substance, exclusive of roots, are produced to the hectare by the average barley-crop of his locality. Now it has been shown, by his own experiments, that barley-plants grown at Dahme exhale, in the course of their lives, an amount of water equal to 310 kilos for every kilo of dry substance produced above ground, whence it appears that 1,023,000 kilos or litres of water will be needed for each hectare of land bearing a crop such as the one now in question. Since a hectare is equal to 10,000 square metres, the amount of water above given represents a rainfall of 102.3 mm. to the square metre, or say 100 mm. during the term of growth of the crop, viz. from the middle of May to the end of July. If the crop were doubled, twice as much water would be needed, and if it were halved, half as much.

During the years 1859 to 1873, the average rainfall for the 2.5 months when the barley was growing was 153 mm. The utmost that fell during this period was 226 mm., and the least 77 mm. But the foregoing calculations have reference only to water exhaled by the crop; no allowance has been made for moisture evaporated from the soil itself, and it is not easy to make such allowance. Still, there is no doubt that large amounts of water do continually evaporate from the soil, especially during months so hot as June and July are, when the barley is growing. It is eminently probable, therefore, that the amount of water exhaled by an average barley-crop, together with that evaporated from the soil, is fully equal to all the rain which falls during the growth of the crop. It is certain, withal, that, on several of the years above mentioned, the rainfall at Dahme was wholly insufficient for the needs of an average crop, even if no account be taken of the moisture evaporated from the soil. Even in the rainiest of years, not so much water fell there as would be exhaled by barley-crops of 46 to 55 bushels to the acre, such as are not unknown in favored regions. It must be borne in mind, moreover, how very irregular the summer rainfall is. There are often long periods without any rain. Showers are sometimes heavy and at other times light. Then, again, different soils vary widely as to their capacity of absorbing and holding the rain that falls upon them. Many soils are cultivated, indeed, which are palpably incapable of holding enough rain-water to support even moderately

good crops. From all of which it appears, again, that the amount of water at the disposition of a crop is a point of paramount importance.

It was for the sake of enforcing this conception that Hellriegel asked the question, as previously stated, Does rain enough fall in a year at Dahme to supply a perfect barley-crop? Even supposing that the rain could all be collected and stored, and be doled out to the crop during the growing-season, the answer is clearly, No: not enough rain falls in that locality in a whole year for the support of a perfect crop, as will appear at once on inspecting the following figures. Hellriegel's best crops yielded at the rate of 42,359 kilos of dry substance to the hectare, which, multiplied by 310, the number of kilos of water exhaled by the plants for each kilo of dry substance produced, gives 13,131,290 kilos as the amount of water required; that is to say, a rainfall of over 1,300 mm. would be needed, while the average yearly rainfall at Dahme is only a trifle more than 551 mm.,— less than half enough for the support of Hellriegel's maximum crops.

It must not be forgotten, however, in respect to ordinary field-crops, that fairly good yields of grain may be got in regions of very moderate rainfall, as in California, provided the rain comes at an appropriate moment. Thus, in the arid Valley of Peshawur, in Northwestern India, where the average annual rainfall amounts to no more than some 15 inches, and the summer's heat is intense, ordinary cultivation is impossible, except by way of irrigation, and yet "About once in every 5 or 6 years, the heavens are bountiful, and an abundant winter rain sends every man out to plough the moistened ground, and throw in his wheat- and barley-seed. The whole valley then is transformed suddenly into one bright sheet of green, and 'the desert blossoms abundantly as the rose.'" (Gore.)

One Reason why Sands are Sterile.

In connection with his discussion of the inadequacy of the summer rainfall, Hellriegel made some highly interesting experiments on the amounts of water that might be held by the soil of fields in his vicinity after these soils had been soaked by the rains of winter. He found that a soil taken to the depth of 32 inches, which consisted of 13 inches of loamy sand tolerably rich in humus, 13 inches of loamy sand, and 6 inches of mere sand, could hold 1,164,483 kilos of water to the hectare; while the same depth of mere sand,

viz. 32 inches, could hold only 418,600 kilos of water to the hectare.

These stores of water would correspond to the amounts supplied by a rainfall of 116.5 mm. and of 42 mm. respectively. They mark the great difference in fertility between such sandy soils, and deep mellow loams fit to hold water, which are capable of being charged with twice as much water as the sand at the start, and which, by retaining a good part of the rain which falls in winter and spring, do actually serve as permanent sources of supply to be supplemented by the summer showers.

Such experiments as these illustrate most forcibly why it is that sandy soils, no matter how heavily they may be manured, can never give such good crops as deep loams unless, indeed, they happen to be placed in good relations with ground-water that is neither sluggish nor too cold. The great merit of loam as compared with sand has been shown directly by the experiments of Lawes and Gilbert, who determined at a time of drought the amounts of moisture contained at different depths, in their somewhat heavy loam resting on clay, both in fallow ground and in a contiguous field where barley was growing. The samples of soil were collected on June 27 and 28, 1870, at 6 different depths, each 9 inches deeper than the preceding, to a depth of 54 inches in all. The barley-roots were observed to have extended to a depth of between 4 and 5 feet, and the clayey subsoil appeared to be much more disintegrated, and much drier, where the roots had penetrated than where they had not. The percentages of moisture found in the soils are given in the following table: —

Depth.	Fallow-land.	Barley-land.	Difference.
First 9 inches . .	20.36	11.91	8.45
Second 9 " . .	29.53	19.32	10.21
Third 9 " . .	34.84	22.83	12.01
Fourth 9 " . .	34.32	25.09	9.23
Fifth 9 " . .	31.31	26.98	4.33
Sixth 9 " . .	33.55	26.38	7.17
Mean (54 inches) .	30.65	22.09	8.56

The rather high percentage of moisture found near the surface, in both soils, was remarkable, in view of the fact that the season was one of unusual drought, but it was partially accounted for by the circumstance that a couple of showers (four-fifths of an inch in all) had fallen upon the land not long before the samples of earth were collected.

It appears from the table that the barley-crop had taken large quantities of water from the land, especially from the upper portions of the subsoil; though, as bearing upon the present discussion, the most remarkable result of the investigation is the very high percentage of water still contained in the subsoil, even of the barley-land, after a long-continued drought. In an acre of the fallow land there was contained, to the depth of 4.5 feet, 2875 long tons of water, and in the barley-land 1951 tons. That is to say, there were about 900 tons less water to the acre where the barley had grown than where the land had lain fallow. But it was argued that the crop need not have exhaled more than 600 tons of water, on the assumptions that the crop amounted to 2 tons of dry substance to the acre, and that 300 lb. of water are exhaled for each pound of dry crop produced. It was urged, furthermore, that since there was so great a difference in the percentage of moisture in the two cases at the lowest depth examined, it is but reasonable to conclude that the difference extended lower still. From all of which it appears that in times of drought crops standing in good loam may depend to an enormous extent upon supplies of moisture previously stored up within the soil.

Merit of Good Seeds.

As has been set forth in a previous chapter, Hellriegel found that the weight of the seed sown had under some circumstances considerable influence on the yield of crop. The heavier the seed, so much the more vigorous is the young plant; but when the growing crop is provided with an abundance of food, under fit conditions, the advantage gained from heavy seed soon disappears. Where the crop is not well nourished, however, the benefit of heavy seed may be traced even up to the time of harvest, though it tends always to disappear. Several experiments which illustrate this point are given in the following table, which shows the absolute weight of the barley-seed, in milligrams (same specific gravity in each case), and the weight of crop harvested 15 days after sowing: —

Weight of the Seed.	Weight of the Crop, Green.	Weight of the Crop, Dry.
20	267	29
30	477	46
40	575	55
50	797	70

It is evident that, with heavy seeds, the probability of getting

a good crop will be increased, in any event; and that such seeds are specially important in the case of forage-crops which are to be mown before coming to maturity, and for countries liable to drought.

Yield of Barley.

Starting from Hellriegel's best crop, grown in a glass jar that contained some 28 lb. of earth, and calculating how much barley could be grown at that rate on an acre of land, it would appear that 18,818 lb. of the grain, i. e. 392 bushels, are possible. In this case some single ears carried as many as 40 or 50, or even 55 kernels of grain. It is hardly conceivable, however, that anything like so large a yield to the acre can ever be obtained in field practice, for plants growing in a field would necessarily be less favorably situated with regard to light than Hellriegel's were, and it would be extremely difficult to supply water in the field so methodically as was done in these experiments. It is to be remembered withal that the ears on Hellriegel's plants were numerous, and that they bore seeds much larger and heavier than those usually grown in the field.

It is true, however, that very large returns of grain have been obtained occasionally by experimenters. Thus, as long ago as 1692, as has been stated in Volume I., a single kernel of wheat has been known to produce 4,000 kernels of grain. In this case, the seeds were sown 10 inches apart, and there was produced from one seed 80 ears with an average of 50 kernels in each ear. It was computed at the time that, on the supposition that the seeds were sown 12 inches apart, and that each seed produced 60 ears with 40 grains to the ear, there would be a yield of 2,400 grains from one; and that at this rate an acre of land would produce 212 bushels of wheat. In actual field practice crops of 90 bushels of wheat to the acre have occasionally been harvested in Great Britain, and it is true of California, notably of the valley of the Sacramento, that there are considerable tracts of land from which crops of 70 to 80 or more bushels of wheat to the acre are harvested not infrequently; in one instance a crop of 108 bushels to the acre was measured. (Semler.)

A French farmer, cited by Duhamel, carefully cultivated a grain of barley which grew by chance in his vineyard in a rich soil, and harvested 4,800 seeds from this one grain, beside straw enough to make of itself a sheaf. Hallier sowed a single grain of barley

in his garden in 1720, and gathered therefrom 154 ears which contained 3,300 grains. It is said that, in a work published in 1594, Sir Hugh Platt depicted an ear of summer barley — grown in land manured with soap-ashes — that was incredibly long.

In England, the yield of barley varies from 15 to 75 bushels to the acre, the average crop being rated at 32 bushels for England and the South of Scotland. We do not do so well as that on this side the Atlantic. The United States census returns of 1870 show averages ranging from 20 to 25 bushels to the acre in most of the states, to 35 bushels in California and Oregon. In Massachusetts, the crop of 1869 averaged 25 bushels to the acre.

Composition of Barley-Plants at different Stages of Growth.

Fittbogen has studied the question as to the periods of development when the barley-crop takes in or produces the largest amounts of organic matter, ash-ingredients, etc., in case the plants are grown under the best possible conditions, according to Hellriegel's plan. He cultivated plants in this way, and collected samples of them at five different periods, as set forth in the following table. Each of his collections comprised twelve plants, which were dried and reduced to powder, and analyzed with the utmost care. At the close of the designated periods, the average development of the 12 plants was as follows: —

No. of the Period.	Date when Plants were taken up.	Length in Centimetres of Stalk or Leaves.	Roots.	Number of the Leaves.	Ears.	Seeds.
I.	22 May	113.4	6,794	70	...	...
II.	2 June	438.2	17,908	113	...	...
III.	16 June	983.4	33,265	120	12	...
IV.	24 June	1,034.8	33,830	123	13	329
V.	16 July	1,098.6	35,489	121	14	326

No. of the Period.	Date when Plants were taken up.	Weight in Grams when dry of the Roots.	Stalks, Leaves, and Ears.	Whole Plant.	Grain.	Straw and Chaff.
I.	22 May	0.979	1.673	2.652	....	....
II.	2 June	2.209	5.801	8.010	....	....
III.	16 June	2.960	12.452	15.412	....	....
IV.	24 June	3.306	16.781	20.087	4.726	12.055
V.	16 July	2.676	19.222	21.898	9.247	9.975

The quantities of organic matter, ash-ingredients, etc., taken in by the plants at the several stages of growth, will appear from the following tables.

One hundred perfect barley-plants contained at the moment of collection the following amounts of substances, in grams: —

No.	Weight of the Organic Matter. Total.	In Roots.	Above Ground.	Weight of the Ash-Ingredients. Total.	In Roots.	Above Ground.
I.	17.979	6.158	11.821	3.860	2.006	1.854
II.	60.752	16.669	44.083	5.139	1.739	3.400
III.	129.694	23.027	106.667	6.230	1.663	4.567
IV.	166.823	25.677	141.146	6.436	1.873	4.563
			41.250[1]			1.000[1]
			99.896[2]			3.563[2]
V.	175.726	20.764	154.962	6.693	1.538	5.155
			74.654[1]			1.388[1]
			80.308[2]			3.767[2]

No.	Weight of Nitrogen. Total.	In Roots.	Above Ground.	Weight of Phosphoric Acid. Total.	In Roots.	Above Ground.	Weight of Potash. Total.	In Roots.	Above Ground.
I.	1.134	0.237	0.897	0.413	0.197	0.216	0.978	0.230	0.748
II.	2.043	0.438	1.605	0.615	0.161	0.454	1.116	0.165	0.951
III.	2.204	0.490	1.714	0.729	0.128	0.601	1.114	0.157	0.957
IV.	2.254	0.642	1.612	0.776	0.097	0.679	0.847	0.159	0.688
			0.661[1]			0.384[1]			0.229[1]
			0.951[2]			0.295[2]			0.459[2]
V.	2.252	0.583	1.669	0.802	0.077	0.725	0.809	0.079	0.730
			0.937[1]			0.566[1]			0.235[1]
			0.732[2]			0.159[2]			0.495[2]

It is evident that the plants continued to accumulate organic matter and ash-ingredients as long as they continued to grow. Nitrogen continued to be accumulated until the end of blossoming. Both nitrogen and ash-ingredients were assimilated with special ease and rapidity when the plants were young, i. e. during the first third of their life. Organic matter, on the contrary, was produced freely until the appearance of the ears. These results are made plain in the following table.

One hundred complete plants took in, absorbed, or produced the following weights of substances, in grams: —

No. of the Period.	Duration of Period, in Days.	During this particular Period. Organic Matter.	Ashes.	Nitrogen.	Per Diem, on the Average. Organic Matter.	Ashes.	Nitrogen.
I.	10	17.979	3.860	1.134	1.789	0.386	0.113
II.	11	42.773	1.279	0.909	3.888	0.116	0.083
III.	14	68.942	1.091	0.161	4.924	0.078	0.011
IV.	8	37.129	0.206	0.050	4.641	0.026	0.006
V.	22	8.903	0.257	0.000	0.405	0.012	0.000

It is to be observed that, although a continual increase of total ash-ingredients was noticed, no such constant increase occurred in respect to some particular constituents of the ashes. Thus there were absolutely smaller quantities of potash, magnesia, soda,

[1] In grain. [2] In straw and chaff.

and chlorine in the plants during the last stages of growth than had been noticed previously.

The largest increase in weight of the crop occurred between the time when ears first appeared and the end of blossoming. A similar observation had previously been made by Scheven in respect to barley, and by Stoeckhardt, and by Wolff also, in respect to oats. But in the field much must depend upon the character of the soil and the state of the weather, and Arendt has studied an oat-crop which took up the largest proportion of its dry matter while it was comparatively young.

Taking the largest observed weight of the roots (dried) as equal to 100, Fittbogen found that there was produced of dry roots, —

	Per Cent.
Before the 1st collection	29.6
Between 1st and 2d collection	37.2
Between 2d and 3d collection	22.7
Between 3d and 4th collection	10.5

From the time of the first appearance of grain until ripeness, the dry matter of the roots diminished to the extent of 19 %.

For each 100 lb. of dry roots there were found the following amounts of dry stalks, leaves, etc. : —

171 lb. at the time of the 1st collection.
263 " " " 2d "
421 " " " 3d "
508 " " " 4th "
718 " " " 5th "

It is of interest to note how different these relations are from those observed by Nobbe in respect to the dry organic matter in the roots and foliage of buckwheat-plants that were grown in garden-loam. He found, namely, for 100 lb. of dry roots, 1520 lb. of dry stalks, leaves, etc.

Relation between Grain and Straw.

The relations between straw and grain in crops of barley as ordinarily harvested in farm practice vary widely in different instances, and the consideration of the causes of these variations is a subject of no little interest. The perfect plants of Hellriegel yielded as a rule about as much dry grain as they did dry straw. His figures are 44 to 48 % grain, 44 to 48 % straw, and 6 to 8 % chaff. Of course every particle of the plant above ground was saved in this case, and no kernel of grain was lost in any way,

while in the field there is much waste, and often imperfect separation of grain from the straw, to say nothing of incomplete translocation of substances from the straw to the seed. It is noticeable that in field practice the proportion of barley-grain to straw is commonly as 2 : 3; under the most favorable circumstances it is seldom if ever better than 5 : 6, and it varies from year to year, according to the weather. Practically, barley-straw is thought to have considerable value as fodder. It is held generally to be better for this purpose than the straw of rye or wheat. Manifestly, the more perfect the growth of the crop, and the more complete the ripening of it, so much the larger will be the amount of grain produced as compared with the amount of straw.

As regards farm practice, all observers agree that the character of any given season will have a very marked influence on the relative amounts of straw and grain that are harvested. Boussingault and Stoeckhardt and Lawes have each in turn called attention to great differences noticed by them in different years. Thus, in the extremely dry year 1841–42, Boussingault harvested 10 lb. of wheat-grain to 11 lb. of straw and chaff, while in the very wet year 1840–41, he got 10 lb. of wheat to 42 lb. of straw and chaff. In England it has been stated that the relations between wheat-grain and straw and chaff are commonly found to lie between 1 : 1.5 and 1 : 2.5. As the mean result of the comparison of 38 selected samples, of a single year, from various localities, Way found the proportion 1 : 1.3. He suggests that some of the large proportions of straw to grain as given by the earlier agricultural writers may be incorrect. Gasparin says it is customary at a locality in southeastern France, where wheat is grown by way of irrigation, to reckon the straw of the crops as double the weight of the grain.

Limitations of Field Practice.

Curiously enough, when the question is considered in how far it is possible in field practice to attain results similar to those of Hellriegel, it will be seen that the farmer has less power over light than he has in respect to any other of the conditions requisite for growing a perfect crop. To control light in agricultural field practice is quite beyond the power of man. The amount naturally available cannot be increased in any economical way, nor indeed can plants grown in the midst of a field, partially shaded as they are by their companions, ever get quite so much light as came to Hellriegel's individual plants that were entirely free from shade.

It is noticeable that Hellriegel constantly encountered differences from one year to another, both as to the amount of crop harvested, and as to the proportion of straw to grain, which manifestly depended on the comparative warmth of the several years.

It is the necessity of depending absolutely on the natural supply of light, and almost entirely on that of heat, which puts limits to the farmer's power of action, and holds him, so to say, in bonds; for every crop has its own peculiar requirements, both as regards light and heat, which he would be glad to have under control. At each period of development in a plant's life there is some special physiological work to be done, that requires some particular amount or degree of intensity as to the action of these agencies, which it would be well to supply or foster if it were but possible to do so. When grain is ripening, for example, the plants need, and they can bear, more heat than would be good for them when they are merely growing. So, too, a wheat-crop needs more heat than a rye-crop, and barley more than oats.

Other things being equal, it is in the last analysis the average heat and light of a locality which determine the kind of crops grown there, and the amounts of each crop that are harvested. In all other respects the farmer has considerable freedom. By deep cultivation he might increase the volume of mellow earth at the disposal of the roots of a crop; by mulching, he could maintain good tilth; and by means of irrigation, water could be secured in abundance. And plant-food in any quantity might be added to the soil, either as manure or in the shape of artificial fertilizers.

As Boussingault has pointed out, the influence of heat on the growth of crops may be well studied on the sides of high mountains in tropical countries. While palms and the like grow at the base of the mountain, maize succeeds best at heights where the temperature is not too high, while wheat may be grown successfully at still higher altitudes. It is true of some of these regions that experience has determined with a considerable degree of accuracy the limits of temperature within which each of the crops above named may be grown with profit.

It might, perhaps, be easy to illustrate upon one or another of these "belts" the proposition advanced in volume I., that the hotter the country — if only it be duly moist — so much the better may farmyard-manure be utilized. It is not improbable, for example, that towards the lower edge of the wheat-belt, on the Andes,

maximum crops of this grain might be got with smaller dressings of manure than would be needed near the upper edge of the wheat-belt. But as a general rule, as regards field-crops, heat is almost as unmanageable as light. It is true that the farmer might establish himself once for all in a hot or a cold country, or he might choose a locality and a climate suitable for the crop he specially affects. He may warm his land somewhat by draining it, or by means of fermenting manure, or by sheltering it with fences or belts of trees, or by strewing dark-colored gravel upon it. Certain plants may be helped by heat radiated from walls, while other kinds that cannot bear intense sunlight can be protected by appropriate shades. But the fact remains that, after having established himself in any one place, the farmer must depend largely upon the heat and the light proper to the locality. In general it may be said that the limits of temperature within which agricultural crops can prosper are not very wide, although some kinds of polar plants can grow in soil and air but little above freezing, and other plants, — notably those in thermal springs — can support temperatures as high as 113° or 118° F. (Boussingault.)

The Germination of Seeds.

In speaking just now of barley-malt, and in some of the earlier chapters also, the germination of seeds has been alluded to incidentally. It is a subject concerning which much might be said. Chemically speaking, the facts to be specifically insisted upon are as follows. When a seed is moistened and placed where oxygen can come in contact with it, in a sufficiently warm place, the process known as germination begins. The conditions essential for germination are moisture, warmth and oxygen; and if one or another of these conditions is lacking, the process will not go on. Even if the process were once well started, it would come to a standstill if the water about the seed were to dry away, or the temperature were to fall, or the oxygen in the circumambient air were used up.

For example, seeds germinate readily when, after having been swollen in water, they are placed in a glass cylinder, which is kept warm, and through which a current of air is continually drawn, to remove the carbonic acid which results from the action of oxygen upon matters in the seeds. But if the current of air were checked so that carbonic acid could accumulate around the seeds, the process of germination would be interrupted; and so it is when

seeds are buried at such a depth in the soil that no adequate supply of air can reach them.

It has been maintained erroneously by Duclaux that the action of microscopic organisms is essential for the germination of seeds, in addition to the mere chemical action of oxygen. In his experiments seeds failed to germinate in a soil that had been "sterilized" in such wise that it was completely freed from all living things. It has even been argued that the observations of Bert, cited on a subsequent page, support the idea that micro-organisms play an essential part in the process of germination, and that the real reason why germination cannot occur in compressed or in rarefied oxygen is that the organisms are destroyed by the untoward conditions. But these ideas have been disproved by several German experimenters, who have found no difficulty in causing seeds to germinate in sterilized soils.

If swollen seeds are laid on muslin stretched across the mouth of a vessel full of water, they do not, as a rule, germinate so well as when placed in clayey loam, manifestly because the warmth evolved during germination is conducted away from the seeds more rapidly in the one case than in the other.

In order that germination on muslin shall be fully successful, it is best to keep the water beneath the muslin warm; that is to say, it should be maintained at the temperature best fitted for the germination of the particular seed upon which experiments are to be made. Some seeds germinate well enough on muslin when the water is at the ordinary temperature of the air, but others do not. It is noticeable that while the seeds of most domesticated, i. e. agricultural, plants can be made to germinate at any season of the year, on exposing them to proper conditions as to temperature and moisture, the seeds of many wild plants, as those of certain forest-trees and of some kinds of weeds, can best be started at particular times and seasons, i. e. after the seeds have lain dormant for some months. It would appear that, through inheritance, such seeds have acquired the faculty of resisting accidental circumstances which might, in nature, tend to lead them to germinate at improper moments, i. e. before the advent of the season proper for the growth of the plants which they represent.

There is another point to be considered in respect to germination on muslin; viz. mere water is apt to dissolve out some albuminoid matters from the seeds, and this solution is prone to

putrefy. To avoid this difficulty, it is well, instead of mere water, to use a mixture of one-quarter of a volume of saturated solution of gypsum, and one volume of water. (Knop.) The lime-salt forms insoluble compounds with the albuminoid matters, and prevents them from coming out of the seed. It is because it has the power to absorb and hold these matters dissolved from the seed, as well as on account of its porosity and its comparative non-conductibility for heat, that clayey loam is a better material than either sand or sawdust in which to germinate seeds. One good way of proceeding is to place the seeds in a flower-pot saucer of common unglazed earthen-ware, which is set in a larger saucer kept filled with water up to the rim of the smaller inner saucer. Another way is to place the seeds on a strip of cotton flannel, and roll them up in it to a cylinder, the lower end of which is left resting in water kept at the bottom of a cup. The roll of cloth, and the seeds in it, are thus moistened by capillary attraction. Yet another way is to sow the seeds in fresh sawdust which has been soaked in water and squeezed hard to expel the excess of moisture. It is well to keep the vessel which contains the sawdust in a warm place, but so to shield or cover it that evaporation shall not be too rapid. Instead of sawdust, practical men sometimes use the loose humus which is found in hollow apple-trees.

Influence of Moisture and Oxygen.

It is to be remembered that a seed contains everything necessary for the development of the young plant excepting water and oxygen. Both these additions are necessary, and they must come from without. Seeds will not germinate in oil; nor in water which has been boiled to expel air; nor in gases other than oxygen. They do not require that the air about them shall contain the full quantity (20%) of oxygen which is usually found in air, though naturally enough too great a reduction in the proportion of oxygen is unfavorable, and germination may wholly cease in air which contains from one-ninth to one-sixteenth of oxygen. Lefebure and Heiden have found that germination is still possible, though much delayed, in air which contains no more than one-thirty-second of oxygen. It appears, moreover, that any marked diminution of the pressure of the air is hurtful, and that in general the process of germination runs its course the more slowly in proportion as the atmospheric pressure is less.

Bert found that, while 85 % of barley germinated at the ordi-

nary pressure of the air (=76 cm. of mercury), only 40 % germinated in air at 50 cm. pressure, 28 % at 25 cm., and 10 % at 6 cm. Practically, germination ceased at pressures between 4 and 12 cm., although the seeds did not die. It did not appear that the trouble was due to mere lack of mechanical pressure, but to the fact that the tension of the oxygen in the rarefied air was too low. It was observed that, in case air richer in oxygen than ordinary air was rarefied, seeds germinated in it as well as in ordinary air at the normal pressure. And Boehm has noticed that germination succeeds even in pure oxygen which has been rarefied to a pressure of 15 cm. mercury, or which has been mixed with four-fifths of its volume of hydrogen-gas.

On the other hand, too much oxygen is hurtful. De Saussure stated in his day, and Heiden has found, by numerous experiments, that moistened seeds kept in an atmosphere of pure oxygen may begin to germinate, though no more quickly than is the case of seeds kept in ordinary air. But Boehm and Bert declare that only the first stages of germination are possible in pure oxygen, at the ordinary atmospheric pressure, and that the process of developing the young sprout cannot go forward unless the oxygen is diluted or rarefied. According to Bert, germination is difficult in air which contains 80 % or 90 % of oxygen, though the young plants develop well enough in air which contains 60 % of oxygen or less. On increasing the pressure of ordinary air to the extent of 2 or 3 atmospheres, germination is not hindered, but perhaps helped a little, though pressures of 4 or 5 atmospheres, or more, are hurtful. At a pressure of 10 atmospheres the seeds are killed, simply because the tension of the oxygen is too great. Even mature plants may be killed when subjected to a pressure of 6 atmospheres in ordinary air, or to a pressure of 2 atmospheres in air rich in oxygen. (Bert.)

It may here be mentioned that experiments by Jentys have shown that, while the growth of young plants is not completely arrested in pure oxygen-gas under pressures greater than that of the atmosphere, it is always retarded, and the more so the greater the pressure. Radishes, mustard and turnips grew better in pure oxygen at atmospheric pressure than in oxygen at lower pressures, though a reduction of pressure had little influence on beans, peas and sunflowers. Compressed air retards growth. The bad effect of oxygen above atmospheric pressure seemed to be due to a di-

rectly poisonous influence, and not to its inability to support the respiration of the plants. It is noticeable that, while the presence of hydrogen or nitrogen as a diluent of oxygen does no direct harm, carbonic acid seems to be actually detrimental to germination.

By the action of air and water, at suitable temperatures, some substance within the seed is transformed into bodies — of which diastase is a familiar example — that are known as "unorganized ferments," and which act to change the insoluble matters of the seed into substances that are easily soluble and diffusible. Some soluble starch is formed, and much starch is changed to the sugars maltose and dextrose, as well as to dextrin, all of which move forward to form cellulose and the other substances which build up the shoot; the albuminoids are converted into amids, such as asparagin, glutamin, leucin, etc., together with a small quantity of peptone, while the oil in oily seeds splits up into glycerin and fatty acids, which absorb oxygen from the air and change to carbohydrates. The glycerin seems to change immediately to sugar and to an acid readily soluble in water. Meanwhile much carbonic acid is evolved, and minute quantities of certain vegetable acids are formed.

Inasmuch as these changes are due to the presence of ferments, known collectively as diastase, the process is really one of digestion, analogous to the digestion of food in the stomachs of animals. It has long been known that a slight degree of acidity is essential for the proper action of the digestive ferments, and it is interesting on this account to note, when a seed germinates, that it soon ceases to be neutral to test-papers, and becomes faintly acid. It is said that the conversion of the reserve matters in seeds to mobile substances, as well as the movements of the latter towards those parts of the plants where they are needed, are dependent on the need, i. e. on the demand made by the new cells of the growing plant. When the progress of a new-born plant is checked by any outside influence antagonistic to growth, the reserve matters of the seed cease to undergo change as soon as a certain quantity of the new substances has accumulated. The presence of this accumulation acts to prevent further changes until the back action is removed at the time when the plant begins to grow again. (Pfeffer.)

The various soluble matters formed by the action of the ferments

pass from the seed to the sprout, and are there changed to cellulose, and the so-called hemicelluloses, to starch, albumen, and the other matters of which the sprout consists. This transference of matter may even go forward, in the case of certain kinds of plants, for some little time from the lower leaves to those which are higher; and the young plants may thus continue to grow in pure water for a month or six weeks, the lower leaves dying, meanwhile, as the upper leaves develop. Of course, under these conditions a little carbon is gained from the air through decomposition of carbonic acid which is absorbed by the leaves; but there is seldom any marked increase of dry matter over what was contained in the original seed. During the mere act of germination, the seed and the sprout naturally lose weight continually, because much of the substance of the seed is converted into carbonic acid, which escapes into the air.

Germination and Growth overlap.

Ordinarily, the young plant begins to take food from the soil and the air before it has wholly exhausted the store of food which the seed supplies to it, and it has been noticed in many instances that, in order to this result, great numbers of absorbent hairs are speedily thrown out from the very first rootlets of the young plant. Ash-ingredients are taken in freely from the soil through these absorbent surfaces before the process of germination has been completed. It has often been observed that the soil of seed-beds is apt to be speedily exhausted, and that young plants usually contain a large proportion of ashes.

The so-called "mother of ferment" in the original seed, through the transformations of which the diastatic ferments are formed, has been named zymogen. Some idea of it may be got from the results of experiments in which non-germinated seeds have been leached with a neutral solvent, such as water, glycerin, or a solution of common salt. It is found that the extracts thus obtained are inert and unable to ferment albuminoid matters or oils. But if, instead of water, the seeds are leached with accidulated water, at a temperature of 86 to 104° F., the extract obtained is fully capable of exciting fermentation. In the case of the castor-oil bean, it has been noticed that the ferment is formed on warming for an hour or two an aqueous extract of the bean to which a little very weak acid has been added.

Sometimes, but not always, considerable quantities of free

nitrogen are evolved during the process of germination, through the decomposition of a part of the nitrogenous matter of the seed, due apparently to the action of micro-organisms. But, as Atwater has well said, germination without microbes and without the liberation of nitrogen appears to be the normal process.

It is important to remember that each and every kind of seed has its own peculiar limits of temperature between which it can germinate. A considerable amount of warmth is generated, of course, by the chemical reactions which occur during germination, but a certain definite external temperature is needed to start the internal development of heat. Maize needs a higher temperature for germinating than barley, rye and wheat, in spite of the fact that the several grains resemble one another tolerably closely in chemical composition. The following examples have been selected from a table drawn up by Van Tiegham, who determined the maximum, minimum and "best" temperatures for the germination of a number of different kinds of seeds: —

	Minimum.	Maximum.	Best temperature.
Mustard	32° F.	99°	81°
Wheat	41	99	81
Barley	41	100	83
Red clover	42	82	70
Peas	44	...	80
Turnips	...	108	89
Maize	49	115	93
Melon	...	...	99

To test this matter, Hellriegel sowed several kinds of seeds, on the 15th of January, in glass jars filled with garden-loam, and placed the jars in a room that stood between rooms that were heated, although it was not itself artificially heated. The earth was kept moist to the extent of 60 % of its water-holding power, and the dates at which leaf-buds appeared at the surface of the earth were noted. Some of the results obtained are given, as an example, in the following table. The mean temperature of the soil was 48° during the experiment, and the range of temperature was between 43° and 53°: —

Kind of Plant.	No. of Seeds sown.	No. of Plants that appeared finally.	At Days after sowing.
Winter rye	10	9	9
Winter wheat	10	10	12
Barley	10	8	13
Oats	15	15	13

Kind of Plant.	No. of Seeds sown.	No. of Plants that appeared finally.	At Days after sowing.
Maize	10	2	42
Flax	10	9	13
Peas	6	6	10
Horse beans	3	3	19
Lupines	5	2	42
Clover	20	17	14
Buckwheat	10	3	16
Beets	20	20	38
Carrots	20	20	38
Cucumbers	10	0	42

There is a curious practice of gardeners which deserves to be studied from this point of view; the custom, namely, of throwing the seeds of certain leguminous plants into boiling water, and letting the water cool with the seeds still in it. This "warming" is of the nature of a strong suggestion that the seeds should enter upon a new course of life. A seemingly analogous practice is said to occur in Calabria, Italy, where the seeds of Hedysarum ("Spanish sainfoin") are strewn on land from which a crop of wheat has just been harvested, and the wheat-stubble is then burned. Next year a heavy crop of Hedysarum is mown in June and the stubble is ploughed under in preparation for winter wheat, an excellent crop of which is harvested in due course. The stubble of this wheat-crop being fired as before, a new (volunteer) crop of Hedysarum is obtained, and this alternation between wheat and the leguminous crop can be maintained for several years without manuring. (Gasparin.) Familiar facts related to this question are the coming in of white clover on land over which fire has passed, and the appearance of "fire weeds" (Epilobium Erecthites, etc.) where forests have been cleared.

In view of the circumstance that a very considerable development of heat occurs when greasy rags, or any organic matter charged with oil, are moistened with water, Ladureau has suggested that heat is probably developed in the same way when oily seeds are moistened. In this view the development of heat by the oil, either through oxidation or ferment action, would start the process of germination, and the other steps would follow in due course.

Soaking of Seeds before Planting.

There are some kinds of seeds — notably those of the carrot,

parsnip and orchard-grass — which are specially apt to fail to germinate from lack of moisture, and no little advantage is often gained by steeping or moistening these seeds before sowing them. It is said, however, that moistened seeds should always be sown in ground that is fairly moist, for dry earth would suck out from the swollen seeds both the water and the matters which the water had dissolved, and would be apt to destroy the vitality of the seeds. By good rights, the soil should be well pulverized and be firmly pressed down upon the seeds, and it would be well to have some rain fall upon it soon after the sowing.

A water-drill, or liquid-manure drill, was used at one time in England for sowing turnip-seeds — especially as a safeguard against the turnip-fly — and it was claimed that considerable advantage was gained by it in places where water was to be had without trouble. Three hundred gallons of water, or of diluted dung-liquor, were mixed with 3 cwt. of superphosphate of lime which by the action of the cups in the drill was converted to a creamy liquor and deposited with the seed along the rows made by the drill. Care was taken to have harrows follow the drill to cover the rows before the sun had time to bake the liquid. This water-drill was found to do its best work in wet weather, and in warm, wet seasons. If the field was moist, or if rain fell soon after the sowing, the germination and growth of the seeds was very rapid. Sometimes guano was applied in this way on strong soils, or a mixture of 1 cwt. guano and 2 cwt. superphosphate.

The extraordinary insensibility of dry, ripe seeds to cold is a fact of no little agricultural importance. It is because of the resisting power of their seeds that so many tropical weeds survive to afflict farmers throughout the temperate zone. In the vicinity of Boston, for example, many of the worst kinds of weeds are cut down by the first frosts of autumn, but those among their seeds which have become ripe and dry suffer no harm, and they germinate in due course next year — after the period of spring frosts — when the soil has become warm enough for their requirements. By using liquified and frozen carbonic acid, Boussingault subjected seeds of clover, rye and wheat to temperatures more than 100° C. below freezing without destroying their germinative power.

Chemicals hinder Germination.

Many experiments have been tried, by different observers, to

test the influence of various chemical agents on the germination of seeds, and it has been made plain by these trials that most saline and acid solutions are detrimental to the process. As would naturally be expected, very many chemical substances which act as antiseptic or germicide agents hinder germination. The cells in seeds will be killed by petroleum, tar, carbolic acid, boracic acid, salicylic acid, or the like, just as any other living organisms are killed by them, and a somewhat similar remark will apply to common salt and to most other saline solutions, unless, indeed, they have been very much diluted with water. More than a hundred years ago Hunter said, "I have sprouted all kinds of seeds in a variety of steeps, and can assure the farmer that the radicle and germ never appeared so vigorous and healthy as when sprouted by elementary water. . . . The same steep when applied in quantities to the soil will undoubtedly invigorate the roots and nourish the plant, but in that case it operates in common with other manures, and loses the idea of a steep. As nitre, sea-salt and lime are generally added to the steeps, I have constantly observed that their application rendered the radicle and germ yellow and sickly."

Indeed, it has been noticed repeatedly by practical farmers that great care should be exercised in all cases where it is deemed advisable to apply common salt, or any other saline fertilizer by drilling it in with the seed, for both seeds and young plants are liable to suffer serious injury when left for some time in contact with soluble saline matters. Schuebler found that 9 or 10 parts of salt in 1,000 parts of earth, either wholly prevented the germination of seeds of cress, vetches and barley, or speedily killed the young plants. Nessler found that most saline solutions stronger than 0.5 % are hurtful, both for seeds and for young plants which have just sprouted. Thus, a 0.5% solution of common salt prevented the germination of clover, rape and hemp seeds, though a solution so weak as this did not prevent wheat from germinating. A 1 % solution of the salt, however, prevented all but a few grains of wheat from germinating, and the sprouts that did start soon perished. Hemp-seeds were injuriously affected by a solution of salt which contained no more than 0.25%.

In Nessler's experiments, wheat germinated when moistened with a 1% solution of sulphate of ammonia, but the young plants would not grow, not even when the solution was 0.75%; and

Bouchardat noticed, as long ago as 1843, that aquatic mints which had been reared in water were killed by adding to the water very small quantities of ammonium salts. He concluded that ammonium salts are poisonous to plants when solutions that contain no more than a thousandth part of the salt have been taken in through the roots. Cloez also noticed that solutions containing no more than one ten-thousandth part of an ammonium salt were injurious to the growth of certain aquatic plants on which he experimented. Nessler found that a comparatively large number of seeds germinated when wet with a 10% solution of sugar. But the growth of the young plants was hindered even by a 0.5% solution of it. Ferrous sulphate (copperas), even when its solution is no stronger than 0.05%, has an injurious effect, both on germination and on the further development of seeds that have already sprouted. These statements consist with the well-known fact that, in water-culture and sand-culture, it is usually the safest to employ saline solutions which are no stronger than one part of the salt to 1,000 parts of water.

In general, seeds that have been swollen by soaking them in water or in harmless saline solutions before planting yield better crops than those sown dry, but there is a considerable risk of injuring the germinative power of the seeds by using saline solutions, or even diluted dung-liquor, instead of water, and seldom is any practical advantage gained, though it is a remarkable and a still unexplained fact, noticed by Wollny, that crops tend somewhat to "run to leaf" when their seeds are swollen before sowing. In the case of beets even, where the seeds had been swollen in dung-liquor, the development of leaves was remarkably large, although the yield of roots was smaller than that obtained from unsoaked seed. Like Nessler, Wollny observed that saline solutions stronger than 0.5% are usually hurtful. A 1% solution of saltpetre, for example, injured both seed and crop.

"Steeping" of Seeds.

It should be said that, as thus applied for actually swelling seeds, the action of saline chemicals must be materially different from that of the solutions of poisons — such as sulphate of copper (blue stone) and arsenious acid — which are often applied to seed-grain in order to destroy any spores of fungi which may happen to be attached to the seeds; such fungi, for example, as might cause the growing crop to "rust," or "smut." Here, the action of the

poisonous chemicals must be largely confined to the external surfaces of the seeds; in all probability it cannot reach the internal organs or much affect the embryo or undeveloped plantlet which each seed contains. A similar remark will apply to the process of coating seed-grain with slaked lime, or with lime and brine, for the purpose of destroying the smut-fungus. It may here be said that a better method of procedure is to throw the seed-grain into hot water, with proper precautions, and so scald the rust-germs to death.

Candying of Seeds.

A common method of applying fertilizers (and germicides), which was practised even by the ancient Greeks and Romans, and by the Chinese, is to encrust seeds before sowing them with a coating of the fertilizing material. This system of "candying" has been repeatedly tested by scientific experimenters, and appears to be worthy, on the whole, of some small commendation. It has been proved of several fertilizers that, when applied in this way in small proportions, they may do good service both by repelling insects directly, and by encouraging rapid growth of the young plant, so that the attacks of insects will do less harm.

But it is recognized that the method of candying is almost always attended with considerable risks. It has been noticed, for example, of such fertilizers as blood and guano, that they may do good when used in moderate doses for candying seeds, while larger amounts are decidedly harmful. On the Orkney islands, it was customary at one time to mix guano with the seed-oats, in order to shield the crop from the attacks of a kind of grub. A place was swept clean upon a road, and the slightly dampened oats were mixed there with Peruvian guano at the rate of some 28 lb. of guano to the bushel of oats. When oats were prepared in this way, 1 cwt. of guano to the acre was thought to be sufficient to apply afterwards as a top-dressing.

Not only might organic materials, such as blood or bone-meal, promote decay, when the conditions in the soil at the time of sowing were not favorable for immediate germination of the seeds; but, as follows from what has been said already of the action of saline solutions — concentrated soluble fertilizers when put into immediate contact with seeds must be liable to injure them, since there may be formed upon the seeds, at the moment when the fertililizers dissolve, more highly concentrated solutions than the seeds can bear.

For testing the significance of candying, Wollny stirred some seeds first in a weak solution of glue, and afterwards in bone-meal, in guano, in sulphate of potash, and in superphosphate made from guano. He found that the germination of the seeds thus candied was usually delayed, and that many individual seeds did not germinate at all; that the growth of straw and leaves was often decidedly promoted, and that in several instances there was a considerable increase in the amount of straw harvested. As to the amounts of grain or seeds harvested, the results were conflicting; sometimes the can-

dying diminished the yield of grain, and at other times it increased it. From the results of his experiments, Wollny concluded that candying is no substitute for the ordinary methods of manuring; that easily soluble chemicals should not be applied in this way unless largely diluted with some inert material such as sawdust; and that — like any other method of manuring seedling plants — the process should be used only on fertile land, well fitted for holding a good store of capillary water and for "fixing" chemical substances. When all these conditions are favorable, candying may serve a useful purpose as a means of forcing young plants.

The most noteworthy result of this research is the discovery of the fact that candying is apt to promote the growth of the leaves and stalks of plants at the expense of the yield of seeds and "roots." This fact is one of deep interest, physiologically speaking, and it may perhaps find practical application occasionally as a means of increasing the growth of forage-crops. In explanation of it, Wollny suggests that the tendency to run to leaf may possibly depend on an actual enfeeblement of the plant, produced at the moment of birth, as it were, by the malign action of the chemical substances. This hypothesis applies as well to the case of seeds that have been swollen in dilute saline solutions before sowing.

CHAPTER XXXVII.

OATS.

THE oat is a hardy plant, specially well adapted for temperate climates. It yields a nutritious grain, beside straw which is held to be worth rather more as fodder than the straw of most other cereals. It is a plant easily grown, withal, even in cold, harsh situations, and on poor soils, since it is robust and vigorous, and capable of feeding closely, as the term is. That is to say, it is not fastidious as wheat and barley are, either with regard to the quality of its food or the tilth of the soil. In my own experience, excellent results have been obtained by sowing oats on a drained bog very early in the spring, when the frozen soil had not yet melted to a depth of more than 3 or 4 inches at the surface. The still frozen ground, which bore up the horses, permitted the use of harrows for covering in the seed. It is held to be well, in any event, to sow oats as early as possible in the spring, to ensure a long term of growth and an abundant yield of grain.

It is because of these considerations that oats are often grown on very poor land. So, too, in some of the older systems of rotation, oats were habitually grown at those times and places when the smallest amount of manure was applied. Yet oats are grate-

ful for manure, and they thrive especially on soils rich in humus. They are frequently grown as the first crop on newly broken sod-land, and on peaty soils. Moreover, oats are often grown after oats for several years in succession, even on rather poor land. There are even instances upon record where oats have been grown 6 or 7 years in succession, on the same land; but in these cases the soil was fertile, and it had previously lain for a long time in grass. (Compare p. 178 of this volume.)

Oats have commonly been regarded as rather an exhausting crop. Perhaps because of the habit of growing them on unmanured land? But Waring has argued that a part of the injury attributed to the hungriness of the oat-plant may be due to the fact that its roots are apt to bind the soil into clods, which are often difficult to reduce. It has been said by some writers that nothing suits the oat-plant better than sod-land, and that, conversely, there is no crop better than oats to grow upon ploughed sods; while others have insisted that the best possible food for the oat-crop is to be found in soils which abound in nitrogenous vegetable matter. Wheat, on the contrary, seldom does well on grass-sod, for it requires a firm soil, and can prosper on a hard one, even harder than could be borne by oats. Instead of taking trouble — as for barley — to plough the land in the autumn in preparation for the spring sowing, farmers commonly plough for oats in the spring, and they may perhaps even prefer to sow the seed on ground that has been freshly tilled.

Oats are not much cultivated in hot countries. In Europe they are rarely seen below the isotherm of Paris, while in Great Britain more than 4,000,000 of acres were devoted to oats in the year 1891, mostly in Scotland and the North of England. In the United States, 738,000,000 bushels of oats were produced in 1891, against 612,000,000 bushels of wheat and 2,060,000,000 bushels of Indian corn. The U. S. census of 1890 reports 28,320,677 acres and 809,250,666 bushels of oats, 3,220,834 acres and 78,332,976 bushels of barley, and 2,171,604 acres and 28,421,398 bushels of rye.

Oats prefer Moisture.

Oats succeed best in cool, moist climates, like that of Eastern Canada, Prince Edward Island, the North of Ireland and Scotland, where grain as heavy as 55 lb. to the bushel is harvested not infrequently, whereas, when grown under unfavorable conditions,

the bushel of oats may weigh no more than 24 lb. A long, cool season of growth favors the development of the plant, which requires a larger amount of moisture than wheat or barley, in the sense that moisture should be accessible to the oat-crop even until near the end of the ripening period. It is said that the grain of barley and of wheat becomes plumper and thinner in the skin when moderately high temperatures prevail during the period of ripening. But oats are apt to lose their plumpness during hot weather, and to become lean and light in weight. On light soils, the yield of oats is liable to wider fluctuations than that of the other cereal grains, because the crop is easily hurt by drought, and because it requires a constant and considerable supply of moisture in order that healthy growth may be maintained. (Russell.) In the vicinity of Boston, oats are not grown, except to be cut green for forage, because of their liability to rust. In the Southern States, and in the South of England even, several varieties of winter oats are cultivated.

Oats not a Fastidious Crop.

In the matter of soil, as was said, the oat-plant is not particular. It will grow upon gravel, or upon clay or peat, provided the latter can be kept free from excessive moisture. It has often been said that oats will grow upon any soil that can be ploughed and harrowed. According to A. Mayer, they succeed better on iron soils — and are better able to withstand the injurious action of sulphate of iron (copperas) — than any other cereal grain or than the grasses.

The yield in this country is from 10 to 12 bushels per acre in the Southern States, to 37 and 40 in Iowa and California, say 28 bushels on the average. It is about 30 bushels in New England. In the best oat districts of England and Scotland they get from 44 to 56 bushels to the acre on the average, though occasionally 90 to 100 bushels to the acre are obtained from fertile fields.

Several interesting experiments have been made by Hellriegel with regard to the influence of moisture and of nitrogen on the prosperity of this plant. Starting with plants in tall pots, filled with sand capable of holding 25 % of water, and mixed with all the constituents necessary for a maximum crop except water, he obtained the following results: —

Moisture in 100 Parts of the Soil.	Per Cent of all the Water the Soil could hold.	Grams of Crop produced. Straw and Chaff.	Grain.	Total Crop.
2½–5	10–20	4.19	1.80	5.99
5–10	20–40	11.78	7.81	19.60
10–15	40–60	13.94	10.91	24.85
15–20	60–80	15.78	11.85	27.63

The plants did not wilt with the lowest proportion of water. Precisely as was the case with barley, Hellriegel observed that the natural rainfall at Dahme is insufficient to insure a maximum crop of oats.

In another set of experiments the plants had everything they needed except nitrogen. The following results were obtained when nitrogen was added in the form of a nitrate: —

Pounds of Nitrogen in a Million lb. of Soil.	Oat Grain harvested.	Oat Grain (calculated).
0	0.330	....
	Gain	
7	0.929	1.168
14	2.605	2.336
21	3.845	3.503
28	6.211	4.671
42	7.030	7.007
56	9.052	9.342
84	9.342	9.342

The point of special interest in this matter is, that similar experiments made with wheat and rye showed that a maximum crop of oats can be grown with a smaller proportion of nitrogen in the soil than is required by wheat, or rye, or barley. This result corroborates clearly the popular opinion as to oats, just now alluded to, and explains and justifies the practices of growing this crop on poor land, and on the least fertile field of a grain rotation.

Hellriegel has concluded, from the results of his experiments, as stated in the table, that 56 lb. of nitrogen to the million lb. of soil are sufficient for a maximum crop of oats, while 63 lb. are needed for a crop of rye, and 84 lb. for a crop of wheat. Taking 56 lb. as the amount really needed, he has calculated the third column of figures in the table, which represents the number of grams of grain which should have been produced by the amounts of nitrogen actually present in the soil in case the action of this element is proportional to its weight. These experiments, it should be said, are perfectly consistent with those of Stoeckhardt, who observed that the growth of the oat-plant is greatly increased by the application of nitrogenized manures, and particularly by such as are easily soluble.

Mixed Nitrogenous Fertilizers good for Oats.

For actual farming practice, Stoeckhardt recommended that the oat-crop should receive a mixture of easily soluble and of difficultly soluble nitrogenized compounds, in order that the young plant might be made vigorous and the shooting plant thrifty by the former, while the older plant should be kept growing by the latter.

This recommendation is based upon the results of experiments which were repeated during several years. Stoeckhardt found that when soluble nitrogenized compounds were lacking, the crop did not prosper in the earlier stages of vegetation, while, if only soluble compounds had been given, the rate of growth fell off too soon after the plants had flowered. This difficulty could probably be met by applying the soluble fertilizer, nitrate of soda, for example, by successive instalments, if that operation were but possible on a grain-field, though it may perhaps be true that the plants need one kind of nitrogenous food when they are young, and another kind later in life. By applying easily soluble nitrogenized manures, Stoeckhardt obtained vigorous plants at the start, a point upon which he insists. He proved, also, that the mass of the oat-plant could be increased by applying manure even after the plant had flowered. Hence he urges that the farmer should not be afraid of wasting manure by applying it to a young or middle-aged crop which happens to be backward, or that has received any check.

Stoeckhardt combats the notion that oats will not profit by a heavy dressing of fresh manure, having found that they bear such manure perfectly well; and he argues that it is a point for each farmer to determine for himself whether he had not better buy manure or fertilizers for his oat-fields, and so get good crops, rather than to scourge the land by growing oats without special fertilization. Farmers in England and Scotland have, in fact, observed that oats generally turn to good account nitrogenous manures which are applied to clays or deep loams; and that the crop is less liable than barley to suffer from over-luxuriance when richly fed. It may be said, indeed, that the oat is a much grosser feeding plant than barley. Field experiments made in Germany by Leydhecker, to test the question at what stage of its development the oat-plant may best be manured with nitrate of soda, go to support Stoeckhardt's idea. For there was harvested, as the average

of several trials with four different varieties of oats, the following amounts of crops: —

Kind of Manuring.	Grain, litres.	Straw, kilos.
No manure	12.75	12.80
Nitrate applied after seeding	15.25	14.02
Nitrate applied when the plants had appeared	16.75	15.92
Nitrate applied when the plants were "shooting"	18.00	16.10

Bone-meal gave Stoeckhardt good results upon oats, even as a forcing manure, in case the bones had been steamed and ground fine, and it had the further merit of supplying nitrogen to the crop throughout its entire growth, almost. But it needs to be said that the Tharandt experimental field was a bottom-land, little liable to suffer from lack of moisture. Enormous crops of oats have sometimes been grown in England after wheat, on rich land, by sowing 2 cwt. of guano before the oats are drilled in, in the spring. "A top-dressing of nitrate of soda is often added, for oats will stand plenty of manuring, and the grain is not necessarily spoiled, even if the crop should lodge." According to Maercker, potassic fertilizers often do good when applied to oats; this crop being much more apt to profit from their application than wheat or barley are.

Influence of Phosphates on the Oat-plant.

The following experiments made by Wolff, by way of water-culture, to test the influence of different quantities of phosphoric acid on the development of the oat-plant, are interesting, as showing how important it is, for successful growth, to have an abundance of this constituent, and how marked an influence it has on the production of the grain in particular. Eight jars, each containing six plants, were filled with a highly dilute solution that contained all the elements of plant-food excepting phosphoric acid, which was added in different quantities, as stated in the table: —

No.	Milligrams of Phosph. Acid in the Solution.	Grams of Dry Matter in the entire Plants.	Grams of Dry Matter in the		Proportion of Grain to Straw.	Per Cent of Phosph. Acid in the Dry Matter.	Per Cent of Phosph. Acid in the Ashes of the	
			Grain.	Straw.			Grain.	Straw.
1	230.4	20.71	5.81	11.05	1:1.9	1.11	43.8	18.9
2	155.4	18.64	3.36	10.93	1:3.2	0.83	40.6	11.8
3	97.9	18.30	2.71	11.05	1:4.0	0.53	39.3	7.9
4	49.4	15.55	2.47	10.23	1:4.1	0.33	37.7	4.4
5	33.0	11.47	1.76	7.25	1:4.1	0.28	...	...
6	24.8	8.94	1.77	5.22	1:2.9	0.27	39.4	6.7
7	14.8	5.46	1.04	3.01	1:2.9	0.27	...	...
8	0.0	2.04	0.34	1.05	1:3.2	...	...	...

The percentage of phosphoric acid in the ashes of the grain shows how strong the tendency of this constituent is to move towards the grain, and the small amount of dry matter harvested when no more than 0.33 % of phosphoric acid was contained in it points to the entire inadequacy of minute amounts of this material to perform the work that needs to be done. The plants in jars Nos. 5 to 8 attained to no great development in any of their parts. Under the influence of the larger amounts of phosphoric acid, the production of grain was abundant, complete and assured.

Composition of the Oat-plant at different Stages of Growth.

The changes which occur during the growth of the oat-plant have been carefully studied by several chemists, notably by Norton, Stoeckhardt, Wolff, Arendt and Bretschneider, as has been set forth in "How Crops Grow," p. 223. The research of Arendt, in particular, was carried out in a very complete and admirable manner, and it is customary to lay special stress upon his results, although it is evident that in several particulars these results are of less general applicability than those of his predecessors.

In order to obtain a uniform material for his analyses, Arendt selected, from all parts of a 3½-acre field of oats, a number of vigorous, well-developed plants, of equal size, — as nearly perfect, in short, as could be found. He dried the plants quickly in the sun, and put them aside for examination. Collections were made in this way at five different periods, representing as many stages in the growth of the crop.

The first collection was of plants about four inches high, with three open leaves, and two leaves about to unfold. The second collection was taken when the plants were about two feet high, just before the end of the period of shooting up. The third collection was made just after the plants had blossomed; the fourth, when ripening had commenced, while the seeds were still soft, though they could be shelled; and the fifth, when the seeds were completely ripe.

The plants of each and every one of these collections were divided, in so far as was possible, into six portions; viz. into ears, two uppermost leaves, three lowest leaves, the upper joint, the two middle joints, and the three lowest joints; and each portion was subjected to analysis by itself.

As one result of this very elaborate research, it appeared that,

although the oat-plant increased in size and weight from first to last throughout its entire life, the rate of increase was surprisingly different at different periods.

By far the largest proportion of dry substance was accumulated during the time when the plant was shooting; while during the period of ripening the gain was very small, and it was mainly confined to the seed.

1,000 whole plants contained at the ends of the several periods, i. e. at the moment they were collected: —

	I.	II.	III.	IV.	V.
Grams of dry matter	456	1,364	1,868	2,324	2,459
Organic matter	419	1,292	1,767	2,203	2,332

In other words, 1,000 plants absorbed, took in, formed or produced during the several periods, —

Grams of dry matter	456	908	504	456	135
Organic matter	419	873	475	436	129

Too much stress must not be laid upon these figures, however, for results obtained by other experimenters show that a crop growing in the field may assimilate more or less of its substance at one or another period according to the weather and the soil, i.e. according as the supply of food is abundant or meagre, and as the conditions essential to growth are more or less favorable. For example, Stoeckhardt and Wolff and Bretschneider, all found in their experiments that the oat-plant usually gains more between the moment when the ear appears and the end of blossoming, than at any other time. Other chemists have noticed the same thing in respect to barley. Lawes and Gilbert have found for wheat that the amount of carbon in the crop was more than doubled after the middle of June, while the nitrogen increased to a much less degree over the same period. Like Arendt, all these investigators noticed the increase of dry matter from first to last. But Stoeckhardt observed also, long before Arendt's research, that, when oats are manured with easily soluble nitrogenized fertilizers, the great increase of growth will occur before the plant comes into flower, and will fall off after the blossoming. This observation evidently explains the apparent anomaly in Arendt's results, for his oats were grown upon a field which had been dressed with guano the year before, and, as he takes pains to state repeatedly, the plants examined were all unusually rich in nitrogen.

Stoeckhardt observed furthermore, that, when the nitrogenized

manure applied was of a kind that is difficultly soluble, the increased growth of the crop due to the manure, though at first scarcely perceptible, endured to a remarkable degree after the time of blossoming. This influence of manure applied late in the plant's life is no more than would be expected from what is known of the action of ammoniacal fertilizers on greenhouse plants. It is a fact familiar to many gardeners, that, when plants upon which flowers are beginning to appear are supplied with easily assimilable nitrogenous fertilizers, or even if their leaves are exposed to ammonia-gas, the activity of growth will be transferred from the flower to the leaves and stem, which assume new vigor and extraordinary luxuriance. The following table, taken from Stoeckhardt's memoir, will illustrate the points just now mentioned. It gives the amount of increase of the oat-crop in pounds per Morgan (= 0.631 acre) during the stated times.

	May 20 to July 5.	July 5 to July 25.	July 25 to Aug. 23.	Total in 96 Days.
No manure	555	545	335	1,435
With bone-meal	570	1,440	1,315	3,325
With guano and nitrate of soda	1,260	2,131	682	4,073

Another experiment illustrating the action of fertilizers which contain organic nitrogen has been reported by a Danish farmer in the following terms. Two hundred and forty square rods of oats that were dressed with 2.5 cwt. of blood manure yielded 1,868 lb. grain and 2,225 lb. straw; with no manure, 1,584 lb. grain and 1,660 lb. straw; increase due to the manure, 284 lb. grain and 565 lb. straw.

Influence of Weather on the Oat-crop.

Stoeckhardt found also that the weather, according as it was cold or warm, moist or dry, had a marked influence on the movement of nitrogenized matters in the plant, not only as to the amount of nitrogen moved, but as to the times, i. e. the periods of growth, in which the movement occurred. The assimilation of nitrogen was checked by the cold, wet weather of the year 1851, for example, and promoted by the warm, dry weather of 1852. Whence the conclusion that, at the locality in question, pleasant, warm weather tends to the production of plump, highly nitrogenized seeds and non-nutritious straw, i. e. straw poor in nitrogen, while unfavorable, cold weather tends to the formation of seeds poor in nitrogen, and of straw rich in that element. Stoeckhardt found

the following per cent of nitrogen in the oat-crops of 1851 and 1852: —

	1851.	1852.
Straw	0.57	0.28
Grain	1.09	2.00

He remarks that he heard constant complaint from practical men of the low value as fodder of the oats harvested in 1851.

Lawes, in reporting, in 1847, upon the growth of wheat during three consecutive years, called attention to the fact that the observed effect of the climate of the three seasons upon the crops was quite in accordance with the general character of the seasons. The lowest weight of the bushel of grain and the largest amount of straw were obtained in that season which had the largest number of rainy days and the lowest temperature. The least amount of straw was got in the driest season, and the finest quality of grain in the hottest summer.

It is true, however, of oats, as it is of other plants, that in each particular locality they tend to acquire peculiar habits of growth according to variations of climate or other local circumstances. Hence the physical appearance of the grain is extremely variable. Richardson found on examining many samples of American oats, that those from Southern States were "large, light, awned, reddish-brown, with inflated husks not nearly filled by the kernel. Northern grain was smaller, more compact, not often awned, with husk better filled. The average weight per bushel was 37.2 lb.; the heaviest coming from Colorado and Dakota weighed 48.8 and 48.6 lb., and the lightest from Alabama and Florida 24.7 and 26.9 lb."

Another illustration of the power of the weather to influence the growth of a crop, even after the time of flowering, is seen in a practice of greenhouse men, of forcing plants which are about to flower to throw out leaves, and to increase the leaves that already exist, in case for any special reason they wish to retard the time of blossoming. To this end, the plant which is just ready to blossom is subjected to "bottom heat," i. e. the pot which holds the plant is set upon, or just above, the hot-water pipes by means of which the house is heated. An abundant increase of leaf-surface is thus obtained, very much in the same way as it would be by feeding the plant with ammonia.

The influence exerted upon the crop by the mechanical condition or character of the soil is of course intimately connected with

the weather. Thus, in the cold, wet year 1851, oats grown at Tharandt, upon very heavy land, contained 1.09% of nitrogen, while another parcel grown upon a less heavy (i. e. a medium) soil contained 1.50%, and still another parcel grown upon a sandy soil contained 1.85%.

Taking all things into consideration, it is not strange that different scientific observers, operating in different places, under unlike climatic conditions, should have got results which vary from one another in several particulars. Compare, for example, Arendt with Bretschneider in "How Crops Grow," pages 224, 226.

Course of Growth of Oat-plants.

It would be quite beyond the scope of this book to give all of the detailed tables which Arendt has drawn up for each of the six portions into which he divided the oat-plant in each of the five periods, and for each of the component substances that were contained in the several portions. The book in which these results were published is in itself a considerable volume. But a synopsis of some of the more noteworthy results may be given in comparatively few words.

During the last half of the term of growth, after the plant had flowered, it may be said that the whole of the increase was on the part of the grain. There was scarcely any increase of dry organic matter in any part of the plant beside the grain, after the period of blossoming; and during the time when the seeds were actually ripening there was a slight diminution in the amount of organic matter contained in the upper leaves, and in the uppermost part of the stem. As for the lower leaves, they ceased to increase at the time of shooting, even before the plant had blossomed. The distribution of organic matter in Arendt's plants at the several stages of development may be seen from the following table. One thousand plants, at the different stages, contained in their several parts the given amounts in grams of dry organic matter: —

	3 Lowest Joints.	2 Middle Joints.	The Uppermost Joint.	3 Lowest Leaves.	2 Uppermost Leaves.	Ear.
When 4 inches high	76.76	....	....	179.86	162.58	....
After the shooting	120.16	178.85	127.88	199.23	286.77	387.34
After blossoming	135.29	228.24	204.28	198.11	327.47	674.02
Beginning to ripen	143.82	237.48	209.89	188.70	334.02	1089.14
Complete ripeness	141.55	231.01	205.84	179.94	327.53	1245.71

And 1,000 plants contained in their several parts the following amounts of ashes, in grams: —

Period I. . . .	3.54	. . . .	. . . .	19.34	13.72	. . . .
" II. . . .	3.16	5.25	4.67	20.88	21.73	15.66
" III. . . .	4.91	11.46	11.32	22.49	24.53	25.70
" IV. . . .	6.68	12.52	12.41	21.31	35.98	31.86
" V. . . .	6.95	13.00	14.16	20.07	38.47	34.29

Formation of Cellulose.

With regard to the separate "proximate constituents" of the oat-plant, it appeared that cellulose is produced most abundantly at the time of shooting. It ceased to increase after the plant had flowered. One thousand plants contained the following amounts in grams of cellulose in the several periods: —

I.	II.	III.	IV.	V.
103	460	565	545	551

The largest absolute amount of cellulose, as well as the largest proportion of it with regard to the other constituents of the oat-plant, was produced during the shooting up of the stalks, and the amount of this increase was not a little remarkable. Any given weight of dry plants contained twice as much cellulose after the shooting as before, but subsequent to that period there was hardly any increase.

An important lesson as to the harvesting of the hay-crop is suggested by these results; viz. that it would not be well to mow grass towards the end of the season of shooting, lest the proportion of mere woody fibre in it when cut at that time should be too large, as compared with the more valuable constituents. In general, a given weight of dry oat-leaves contained less cellulose than the same quantity of stalks. In the dry leaves the per cent of cellulose ranged from 22 to 38. Up to the time when the plants blossomed, the percentage of cellulose was largest in the upper leaves; but afterwards it was largest in the lower leaves, because, as other substances passed into the upper leaves when the plants began to ripen, the proportion of cellulose there was diminished.

The least percentage of cellulose was in the ears, and it decreased moreover in these organs regularly as they grew older, and so became charged with other matters, from 27% at the time of flowering to 12% when fully ripe. The proportion of cellulose was always smaller, however, in the ears than in the leaves; and all the leaves put together did not contain so much of it as the mature stalk.

Formation of Carbohydrates.

Throwing together the whole class of non-nitrogenized nutritious

substances, such as starch, sugar, pectose, gum, etc., it appears that more of these things were produced during the shooting of the plant than at any other time, and that the least quantity was produced at the time of ripening.

On the whole, the stem is richer in these non-nitrogenized elements of food than the leaves; but as the plant grows older, the proportion of these ingredients increases in its uppermost parts, so that the higher leaves become comparatively rich in them. During the period of ripening, the proportion of the non-nitrogenized matters decreases to a notable extent in the middle and upper portions of the stalk, while it increases in the upper leaves and in the ears. It is evident that some of these matters are at that time transferred from the stem into the fruit and towards the fruit. Their increase in the ear is constant, from first to last. The large proportion of these matters in all the parts of the young plant is noteworthy.

One thousand plants, at the different stages, contained in their several parts the given amounts in grams of the non-nitrogenized elements of food: —

	3 Lowest Joints.	2 Middle Joints.	The Uppermost Joint.	3 Lowest Leaves.	2 Upper Leaves.	Ear.
When 4 inches high	46.47	....	....	83.10	71.85	[201.40]
After the shooting	60.91	91.89	68.97	79.37	106.10	217.47
After blossoming	66.90	124.95	99.51	82.36	139.44	424.02
Beginning to ripen	74.00	131.35	93.95	77.13	159.87	701.88
Complete ripeness	73.84	124.40	89.69	79.44	161.12	811.48

And 1,000 grams of the dried plants contained, at the several periods, these amounts in grams of the non-nitrogenized matters:—

Period I. . . .	566.08	.....	.....	416.87	407.56	.....
" II. . . .	493.73	521.75	512.55	360.62	344.21	539.53
" III. . . .	477.17	521.25	461.56	372.39	393.28	605.65
" IV. . . .	491.67	461.05	449.62	367.32	491.98	626.17
" V. . . .	497.22	446.83	431.39	397.24	439.81	634.59

Formation of Albuminoids.

Nitrogenized ingredients were found in the largest proportion in the very young plants; but as the plants grew older, the proportion of nitrogen fell gradually, while that of cellulose increased, until after the time of flowering, when (with the beginning of ripening) the amount of nitrogen suddenly increased to a remarkable extent, as will appear from what follows. One thousand plants took in (or formed) of nitrogenized matter, while very young, 95 grams; while shooting, 64; while flowering, 44; be-

tween flowering and first stages of ripening, 115; and during the last stages of ripening, 34. The young plants contained the following per cent of nitrogen: —

In the Stem.	In Lower Leaves.	In Upper Leaves.
2.15	2.34	3.74

But so far as these organs were concerned, the proportion of nitrogen in them diminished regularly as the plant grew, so that at the time of ripening the proportions were 0.79, 1.43 and 1.74. A table showing which parts of the plant were richest in nitrogen at the several periods is given in "How Crops Grow," page 231.

Until the grain begins to ripen, the leaves are richer in nitrogen than the ears; but during the process of ripening a large quantity of nitrogenized matter moves out of the leaves and stem into the ears, and from the lower leaves into the upper leaves. The upper leaves are, as a rule, richer in nitrogen than the lower, the tendency of the albuminoids being always to press forward in that direction. It is very noteworthy that about two-fifths of the entire nitrogen in Arendt's crop were taken in between the time of flowering and that of very partial ripeness at which he made his fourth collection, and it was precisely at this period that nearly two-fifths of the entire organic matter of the plant were produced. But, as has been said, Arendt's plants are known to be peculiar, in that they were unusually rich in nitrogen, as was perhaps no more than natural, in view of the fact that they were selected plants, chosen for the very reason that they were vigorous and luxuriant.

Migrations from Roots, Husks, etc.

As for the roots of oat-plants, experiments by Stoeckhardt have shown that they gradually become poorer and poorer in nitrogen as they grow older. Thus, in his crop of 1852, equal weights of roots contained sixteen times as much nitrogen when young as when ripe, and twice as much at the time of flowering as when ripe. It would appear from this observation that an oat-crop which has been mown for forage, while still green, must leave the land in better condition for the growth of a subsequent crop than if grain had been allowed to ripen on the plants.

Stoeckhardt found also, with regard to the husks of oats and other grains, that, although they finally give up the greater part of their nitrogen to the grain, and are consequently poorer in that element in proportion to their age, they do, nevertheless, still

contain when ripe so much nitrogen that they are at least as rich in that element as the leaves, and much richer than the straw. This "chaff" is comparatively rich in mineral matters also, and the use of it as fodder is justified by these facts, to say nothing of the light grain and seeds of weeds which are apt to remain admixed with it, or of the more perfect mastication of the grain which is ensured by feeding it admixed with chaff.

So too with the straw of oats, which is commonly held to be a more valuable fodder than the straw of other kinds of small grains. Partly because of the grass-like character of the oat-plant, the relations between the quantities of grain and straw produced by it are subject to wide variations according to differences of soils and seasons, sometimes as much as 90 lb. of grain have been harvested for each 100 lb. of straw, while at other times the proportion is as low as 30 to 100. Gasparin admits that 62 lb. grain to 100 lb. straw may be an average yield. If the crop were to be left standing in the field during the period of ripening, the grain would not come to complete maturity all at once, but some seeds on each plant would become over-ripe while others were still green. Hence it is important not to postpone the harvest until all the seeds are ripe, but to cut the plants rather early and allow the grain to ripen off in the sheaves and stooks. By so doing much less grain will be lost by shedding and much better straw will be obtained. It is a popular opinion that oat-straw when cut early may be nearly as valuable as hay.

Arendt gives tables to show the gain in per cent of each of the proximate constituents of the plant in the several periods, as follows: —

	Cellulose.	Fat and Wax.	Non-nitrogenized.	Nitrogenized.
I.	18	20	25	27
II.	63	30	32	18
III.	19	35	23	7
IV.	0	15	12	38
V.	0	0	8	10

Also to show the proportion of each ingredient at each period, assuming that the amount of it in the ripe plant is equal to 100: —

I.	18	20	15	27
II.	81	50	47	45
III.	100	85	70	52
IV.	100	100	92	90
V.	100	100	100	100

Ash-ingredients are Variable.

Ash-ingredients were taken in by Arendt's plants continually until the grain was ripe, though the amount fixed tended to diminish as the plants grew older, and it received a decided check towards the close, when the cell membranes had become comparatively thick and hard. One thousand plants fixed the following amounts of ashes, in grams, in the several periods: —

I.	II.	III.	IV.	V.
36.60	33.48	30.33	20.34	7.18

It is interesting to observe that these quantities are not proportional to the amounts of dry organic matter formed in the same times, for these last are: —

419	873	475	436	129

This want of relation doubtless depends upon the fact that a good part of the ash-ingredients of every plant are accidental and useless. The largest proportion of ashes (10.5%) was found in the ripe upper leaves, and the smallest proportion (2.56%) in the lower joints of the stalk at the time of shooting.

The percentage of ash in the ears decreased constantly in proportion as the grain increased in size, so that when the grain was ripe the percentage of ash in it (2.68) was almost as low as the smallest amount observed in the stem (2.56). Arendt has dwelt at some length upon the distribution of the several kinds of ash-ingredients, and upon the times when they become part and parcel of the plant, but his results in that particular have not been supported by those obtained by subsequent investigators. Indeed, it does not appear that any assured knowledge upon these points has been acquired as yet, and it is plain that a crop, accordingly as it grows more or less vigorously at one time or another, may assimilate ash-ingredients in very different quantities, and at different stages of development.

New Oats unfit for Working Horses.

There is one curious point in respect to the ripening of oats that has never been accurately studied. As all horse-keepers know, new oats are unfit to be given to working horses. They loosen the bowels of the animals, make their flesh watery, or "soften them down," as the term is; i. e. they render animals apt to sweat easily, and, in general, put them "out of condition." How or why the new oats produce these effects is not known; but in the course of a few months after harvest, and especially after

cold weather has set in, the oats undergo a change of some kind, either of after-ripening or of fermentation, and are thereafter fit to be fed out to horses. Probably this difference between new and old oats depends upon a change in the chemical composition of some one peculiar, and so to say medicinal, constituent of the oat-grain.

Do Oats contain an Excitant?

Another point to be noticed is the power of oats to excite and enliven, as well as to nourish, animals that feed upon them. It has long been debated whether there is not some peculiar chemical substance in this grain possessing medicinal properties to which the peculiarity now in question may be attributed. It seems probable, for example, that the superiority of oats to maize as food for horses which are to be driven rapidly must be due to the presence of an excitant in the oats. As every American farmer knows, slow-moving draught-horses may be advantageously fed with maize; and it is commonly believed in this country that more hard work can be got from corn-fed draught-horses than from those fed with oats. But it is notorious that driving-horses to which no other grain than corn-meal or cracked corn is given are apt to be "heavy," clumsy, and disposed to stumble, and it may well be questioned whether the popular prejudice that "corn-meal is bad for horses' feet," does not depend on a mere lack of "spirit" or animation.

Vogel declared, long ago, that the exciting constituent of oats is contained in the oil which can be extracted from the grain. More recently, a French veterinary surgeon, Sanson, claimed to have discovered in oats a particular substance, which he called "avenine," which has power to produce nervous and muscular excitement in horses to which it is administered. But chemists who have repeated Sanson's experiments have not been able to find in oats any such substance as he described.

Sanson urged that crushing or grinding oats considerably weakens their power of excitation, and the point is of interest as bearing on the common practice of feeding oats whole, in spite of constant and familiar evidence that the grain is not completely digested by horses when eaten whole. Every day, poultry, pigeons and sparrows may be seen getting their living by picking out incompletely digested oats from horse-dung, and sparrows, at least, seem to prefer these half-digested kernels to the fresh grain. It

would be of interest to determine, by experiment, whether large consumers of oats might not find it profitable to crush the oats immediately before feeding them out.

On seeking to determine what proportion of the oats fed to horses may be lost through incomplete digestion of the kernels, Moser found a total loss of 29 %; and he says that albuminoid matters and carbohydrates contributed to this loss to the extent of one-third of their original amounts. Yet, in spite of this large amount of waste, whole oats are ordinarily preferred for horses, unless, indeed, in the case of some special animal that happens to be old, infirm, or incapable of chewing properly.

CHAPTER XXXVIII.

ESTABLISHMENT AND MAINTENANCE OF HAY-FIELDS.

There are many chemical questions relating to the cultivation of grass and the curing of hay which are still open for discussion. It would be extremely interesting, for example, to know precisely what kind of land is best suited for any given kind of grass, and why. Every farmer would be glad to know what kinds of grasses are best adapted to his own particular fields, and to know just what condition the soil should be brought to, in order to the utmost economy of production, both as regards fertility, firmness, and fineness of tilth, and in respect to moisture at the moment of sowing, and throughout the year.

Even the amount of seed to be sown on a given area is in some sort a chemical question, since the plants that spring from the seeds will struggle with one another for food, and will grow and feed differently, according as they are crowded or not. The depth at which the seeds should be buried manifestly depends on chemical considerations, — and it is, by the way, one of the most important points that the grass-farmer has to consider.

How much and what kinds of manure should be applied to grass-lands, and at what times, are other questions of very great importance; and so is the question in how far can the mulching of grass-fields be made to supplement the process of manuring, or to make good a lack of manure.

The whole history of the growth of the crop, i. e. the knowledge of its condition and quality at different stages of growth, and the

finding out of the best possible time for the cutting of grass, are matters which will be determined ultimately by the aid of chemical investigation.

So, too, with regard to the curing of hay, there are problems relating to the rapidity of drying, to the condition of dryness in which hay had best be housed, and to the comparative merits of storing it in barns or in stacks. It is still a matter of dispute among some farmers whether new-mown grass should be spread in the sun, or be allowed to dry out slowly in swaths and windrows and cocks.

Then, again, how shall mowing-fields be taken care of when once they have been established? Shall the sod be broken up every few years, or will it be well to try to keep the field in grass continuously for generations, as is sometimes done in Europe?

For the sake of convenience, it will perhaps be best to divide the study of grass husbandry into two sections, one of which shall relate to the hay-crop proper, and the other to pastures and the care of them. And first as to hay, which is a highly important crop throughout the Northern United States.

Timothy preferred for Hay in America.

In New England, farmers have long been accustomed to look upon timothy (Phleum), or herd's-grass, as the local name is, as the representative grass, and to hold that it combines all the excellences which are to be found in a grass. The utmost they are ready to admit is, that a mixture of timothy and red-top (Agrostis), or of timothy and clover, may often be advisable. It is probable, however, that this conception as to the supreme merit of timothy may include a considerable amount of error, and that sooner or later the discovery will be made that there are several other grasses worthy of being cultivated in this region, each of them in the places best suited to it. It would be indeed strange if, among the three or four thousand kinds of grasses now known to botanists, there should happen to be no more than one or two kinds suited to the climate and requirements of the Northern United States. It is admitted, as regards red-top, that it makes good hay — which is perhaps more highly esteemed for oxen than for horses — but the heavier varieties of this grass only succeed really well on land that is decidedly moist.

Possibly this wellnigh exclusive growth of timothy is somewhat a matter of fashion, akin to the preferences for Baldwin apples

and Bartlett pears which prevail in the same locality. Perhaps this fashion may die out in time, as that for the varieties of fruit just mentioned assuredly will, to judge from past experience relating to other varieties of fruit, now obsolete, which were formerly esteemed. It is noticeable, even now, that many pomologists stoutly deny the suggestion that the Bartlett pear is a fine fruit. Nevertheless, experience has taught that several kinds of grasses which are esteemed in England — notably ray-grass — do not succeed very well in the Northern United States, and it may still be well, especially when speaking to New Englanders or to their descendants in Western States, to regard timothy, or a mixture of timothy and red-top, as the normal grass for hay.

As will be shown directly, timothy has one great advantage, in that it yields a very heavy burden of fairly good hay. It succeeds well on rich loams, even on peaty loams that have been well mixed with sand or gravel; and although it needs a fair supply of moisture in order that it may do its best, it is still true that on occasion it can support drought better than several other of the cultivated grasses, such as the meadow foxtail (Alopecurus), for example. It is said that, on the peaty fenland farms at the East of England, timothy began to be grown towards the middle of this century, and was considered to be an important acquisition. But timothy is not in the least adapted to support long-continued hardship, such as insufficient food or permanent lack of moisture, and it is a mistake to sow it on land subject to these conditions. There can hardly be any adequate profit in growing this grass on light, dry land, where most of it will die out in the course of the second year. On wet clays, also, it is often difficult to establish either timothy or clover, although several other kinds of grasses may grow very well on such land as is seen not infrequently in old pastures.

Methods of preparing Land for Grass.

There are two or three different methods of laying down land to grass, from the consideration of which some ideas may be got as to the condition in which grass-land needs to be kept. In the vicinity of Boston, the commonest method is to till the soil during two or three years with hoed crops which are well dressed with manure, and then to seed down to grass, either with or without an addition of grain. By the continued tillage, the soil is made crumbly, the manure is evenly distributed, and good fermentation

is ensured, while the land is cleansed from weeds, and it may be improved as to its capillary condition. Moreover, the tillage and the exposure of the soil to the winter's cold tend to destroy many pernicious insects. In the old world, great stress is apt to be laid on the fact that the cultivation of sod-land, there, is often extremely difficult, because of the multitudes of insects and worms which have accumulated during the years that the land has been kept in grass, and which not infrequently devour the crops which were sown after the grass.

Another way of proceeding is merely to spread manure upon an old grass-field that needs to be renovated, to plough under the sod and sow grass-seed immediately, without any other tillage than that needed to smooth the furrows and prepare a seed-bed. This method is specially well suited to low-lying lands, where no great importance need be attached to the improvement of the texture of the soil. In such situations, manure may be used which is highly charged with the seeds of weeds, for when such manure is spread upon the old sod, and ploughed under with it to a depth of 6 or 8 inches (or more), enough soluble fertilizers from the manure to start the growing grass will speedily be drawn up into the seed-bed, while the buried weed-seeds remain so far removed from the air that very few of them germinate, and many of them may decay. Meanwhile the growing grass-roots soon reach down to the layer of manure. In case the buried manure were not particularly rich in soluble matter, it might be well, after the ploughing, to dress the seed-bed lightly with bone-meal or superphosphate, or with a mixture of superphosphate and nitrate, to ensure a good start to the young grass.

Inasmuch as one of the strongest motives for breaking up old mowing-fields in this vicinity is to kill or check wild grasses and weeds which have "worked in," the method of simply turning under the sod may often serve a fairly good purpose, particularly on fields where the ground-water is not too far from the surface; and, if good, it is manifestly to be preferred to the other on many farms where hay is the chief crop. Wherever a fair profit can be got from maize, potatoes, roots, or other hoed crops, it would probably be best to interpolate such crops between the grass-fields according to the usual method, and thus charge the land with manure, and bring it into a good state of fermentation. Meanwhile the land might be freed from some objectionable insects, such as

the grub of the June-beetle, which, in dry seasons, often destroys much of the grass in high-lying, old fields, even those which have been top-dressed. There are some kinds of weeds, withal, which can hardly be destroyed in grass-land except by the interpolation of hoed crops. For example, the common milk-weed or silk-weed (Asclepias) has in recent years become a serious pest in the hay-fields of New England, because profit can no longer be got in this locality by growing hoed crops in rotation with grass. The milk-weed has powerful root-stalks, like asparagus, which cannot be pulled up, and from which new shoots are sent up incessantly as often as the plant is cut off above ground. The carrot (run wild) is another weed which, from its habit of growth and time of blossoming, is not easily dealt with in old grass-fields on poor, dry land, except by the use of instruments of tillage. But it is none the less true, that the practices of most European countries where pastures and mowing-fields are kept up for centuries, and are the more highly esteemed in proportion as they are older, go to show that rotation is in no wise essential for the successful cultivation of grass.

Grass does well on Firm Soils.

Beside the palpable advantage of thoroughly admixing the earth and the manure by processes of cultivation, and of cleansing the land from weeds, it is customary to urge the importance of bringing the land into a good capillary condition, and to insist that frequent ploughings are essential preliminaries to the act of seeding down land to grass; and it would seem at first sight as if there were small room for doubt as to the benefits derivable from deep and thorough tillage, at appropriate seasons, in a climate so dry as ours. The power of tilling deeply and frequently is doubtless one of the merits of that system of seeding in which hoed crops precede the grass. But it is evident enough that the soil of many of the old European grass-fields and pastures, on clay lands, for example, must be decidedly compact, — far more compact, indeed, than the soil would be after harrowing, and during the process of decay, on a field where the sod has been inverted.

In view of the familiar fact that "heavy," firm soils are often called "natural grass-land" by practical men, it may well be questioned whether the young grass-plant does not, as a general rule, grow best on land which is tolerably compact. As Gasparin has set forth, many plants with horizontal roots may be grown

with success on soils which have been stirred at the surface, but not to any great depth. The analogy of the wheat-plant, which needs a firm footing and will not thrive on loose soils, suggests the inference that grass, also, may perhaps prefer such conditions, and the absence of good grasses from land which is devoted to hoed crops supports this idea. It is not the merchantable grasses, but a variety of grass-weeds which spring up on recently ploughed or hoed land.

In this point of view, it may perhaps be better to plough land in the autumn, as a preparation for seeding it in the spring, rather than to plough in the spring. I have myself, on one occasion, obtained an excellent "catch" of orchard-grass at the end of May — on a field that had not been ploughed since Indian corn was planted upon it the year before — by simply harrowing the land lightly, bushing it smooth, and rolling-in the grass-seed, without manure or admixture.

As bearing upon this question, a North German method of improving moor-meadows may here be cited. When a meadow has "run out," and become filled with moss and wild grasses, the plan is to drain the land thoroughly by means of open ditches, and to compost the sods and mud which have been thrown from the ditches, either with dung or with lime. During the winter or early spring this compost is sledded upon the field and left in little heaps, which are spread, after the snow has melted, when the compost has thawed sufficiently to admit of its being shovelled.

As soon as the frozen soil of the field has begun to thaw, i. e. when it has melted at the surface to a depth of 2 or 3 or 4 inches, while the earth below is still frozen hard, a mixture of two-thirds red-clover-seed and one-third timothy (and red-top) is sown upon it, at the rate of 12 lb. or more to the acre. After the seed is sown, the land is immediately harrowed and cross-harrowed — "at first at a walk and then at a trot, the more vigorously the better" — until the melted surface-soil has been changed to a layer of mud. The teeth of the harrow, sliding upon the layer of soil which is still frozen, tear up the old sod very completely, and they rake out the moss also, "often in incredible quantities," while the horses find firm support on the frozen earth.

As has been said already, it is held that this work can only be done effectively at a time when the soil is still frozen hard below, though somewhat melted at the surface. It is thought to be an essential condition of success that the compost, the scarified sod, and the grass-seeds shall be intimately worked together to the condition of a thin mud, — "the thinner the better." The moss is left lying upon the land where the harrow put it, and is thought to do some good by shielding the young grass from frosts. The field may be mown in August, and pastured also in late autumn, but should be rolled the

next spring, to smooth out the cattle-tracks. It is to be remarked, however, that this method could hardly be applicable to bog-meadows (bottom-lands), in which the soil melts in the spring below the surface before it melts at the surface, as will naturally happen where there is an adequate movement of ground-water beneath the surface of the land.

It is true that the reproach is often made against permanent grass-lands, that since tillage and cultivation are notoriously beneficial to the soil, the lack of them must be hurtful, or at the least inadvisable. The argument is urged, that land which is never cultivated cannot be used to the best advantage, and that the exclusion of tillage from any particular fields can hardly be consistent with the most profitable use of those fields; and the same kind of objection will apply with a certain degree of force to the practice of seeding down to grass upon an inverted sod. But it may be answered to this claim, that it seems little short of absurd to break up old grass-fields in situations not specially adapted for tillage,— such as steep, dry hillsides, for example, — when there is no urgent call to do so. In the supposed case, ploughing would destroy the native grasses, which have had no little trouble to work in and establish themselves, and, by the terms of the statement, the place is not well adapted for timothy or clover. On many moist clays, also, it may happen that grass-fields can be maintained most economically by occasional top-dressings.

It has even been urged, sometimes, that the fact that the amount of organic matter (humus) is found to increase from year to year upon permanent meadows is an indication that the maintenance of such meadows must be irrational, since it shows that not enough air can come to the soil properly to oxidize its components. But there are several advantages derivable from permanent mowing-fields that may much more than offset this particular objection, and in general it may be said that the small amount of labor required for the maintenance of permanent meadows would always give them precedence if it were but possible to get from them as large crops of hay as are grown upon new fields immediately after a year or two of tillage.

Against the idea of seeding to grass upon ploughed sods, some foreign experience as to the preparation of pastures (on clay-lands) should perhaps be cited. Several English writers have stated that when an old pasture has become foul and unproductive, it is best to pare and burn the sods, and to spread the ashes upon

the land for a turnip-crop (to be fed off to sheep upon the land), and then to lay the land down again to grass. This method, they say, is very much superior to the plan of ploughing under the sod and then seeding.

Stirring the Sod of Mowing-fields.

An experiment worth trying in certain cases, when seeding to grass on sod-land, would be to run a subsoil-plough through the furrows when the sod is turned. By so doing, the objection as to inadequate tillage might be very much weakened, or perhaps wholly done away with.

The mere stirring of the sod of old grass-lands has often been found beneficial. Thus a Massachusetts farmer reported some years since that he once, early in August, ploughed for half a day an old sod of 16 years' standing, and during the next half-day occupied himself with his team and plough in turning this inverted sod back to its original position, i. e. grass side up. During the autumn, the piece thus ploughed grew green and strong, and could readily be distinguished from the rest of the field. Next year the crop of hay from the ploughed patch was at the rate of 1,300 lb. to the acre, while that from the adjacent unploughed land was at the rate of only 600 lb. to the acre. The good effects of this ploughing are said to have lasted during four years. Perhaps a part of the benefit obtained in this case may have come from the partial top-dressing of earth which the plough must have turned up, and it may be that the bringing up of buried seeds and the pruning of the grass-roots were beneficial, but the inference is that the loosening of the soil was the principal advantage.

The question presents itself, whether, instead of turning the sods in this way, a considerable advantage might not be gained by running a subsoil-plough directly through the grass, at stated intervals, across the field. A "subturf" plough has been invented and used in England for this purpose. But it has been suggested in this country that, by putting a wheel on any good subsoil-plough of moderate size, and running it through old sod to the depth of six inches or so, very effective work may be done at small cost for labor. The proposition was to make the cuts 12 or 14 inches apart in good growing weather in the spring.

It would probably be well to follow the plough with a smoothing-harrow, to scatter a small quantity of seed, and to roll lightly. The plan deserves to be tried on fields that have been so long in

grass that there is danger of the crops becoming "bound out," as the term is; for it seems plain that any process of cultivation that can enable the soil to hold water to advantage, so that the crop may better withstand summer droughts, must be good for grass. There must be, in this sense, many fields where ordinary subsoil-ploughing could be resorted to with advantage, just as, on the other hand, there are clay-soils where the yield of grass might be increased materially by means of tile-drains, though in either event the cost of obtaining the increase would need to be considered.

A plan somewhat similar to the foregoing was carried out at the middle of the last century by a French farmer, cited by Duhamel, who set 3 or 5 coulters on a wide plough-beam in such manner that the coulters should enter 5 or 6 inches deep into the ground, and cut the sod into parallel strips of about 3 inches' breadth. This instrument was drawn with ease by a pair of horses, and the effect of it was to extirpate moss and to greatly enliven the grass. Sometimes a top-dressing of thoroughly rotted dung was strewn with advantage upon the scarified sod.

Spring or Autumn Seeding.

The practices of farmers in Massachusetts with regard to the seeding of grass-fields have changed considerably during the last half of the 19th century. Formerly the spring was esteemed to be the best season for sowing grass-seed, and this notion still persists in Maine. But nowadays late August and early September are very much preferred by most farmers in Massachusetts, excepting some exposed situations upon the seaboard, where there is little or no snow in winter, and where long-continued moist weather is apt to occur in the spring. Probably the spring would be the best season for sowing grass-seed if it were not for the summer droughts, which "burn off" the young grass, as the term is, and encourage a great growth of weeds that check it, though at the best no more than a light crop of hay can be harvested the first year from grass-seed which has been sown in the spring, while the first mowing of grass which has been sown in the autumn may yield a considerable burden of merchantable hay.

In case grass is to be sown in the spring, it will probably be well, in most cases, to sow rather early, in order that the young plants may have opportunity to become somewhat firmly established before the ground gets to be warm enough to encourage the growth of those tropical weeds which thrive so luxuriantly in mid-

summer. Large quantities of water are consumed by these weeds, and if continuous dry weather should occur, near Boston, in late June and early July, grass which had been sown in the spring on foul, light, high-lying land, might be unable to withstand the competition of the weeds, and it would be liable to be utterly destroyed from mere lack of moisture. But if the grass is once thoroughly well started, it may hinder some of the weeds from germinating, and may be able to cope with those which do germinate, unless, indeed, the drought be exceptionally severe. On low-lying land, where there is no lack of moisture, the burning off of spring-sown grass is less to be feared, though even here autumn-sowing is generally preferred.

It is always to be remembered that grass-seed and the cereal grains can germinate and grow at much lower temperatures than most of the really hurtful weeds. Gasparin has insisted — that beside all risks from drought in late summer — it is not well to sow winter-grain too early in the autumn in his locality (Southern France) because of the competition of weeds. It is well to wait, he says, until the time when the nights have ceased to be hot, for in case the grain were to be sown earlier than that time, the growth of the young plants might be hindered not a little by weeds such as would not cause the least annoyance a little later in the season.

Frost Destroys many Weeds.

Manifestly, this reasoning might apply to grass also, in some particular cases. Indeed, it may always be counted as one advantage in favor of the autumn sowing of grass in northern countries that many of the weeds which spring up when the ground is loosened at that season are cut off by frost while still young, and are thus put out of the way of doing any serious harm to the grass. But it has been said of England that there is a risk attending autumn sowing, in that young clover is liable to be greatly damaged by slugs and the winter's frost.

When grass-seed is to be sown upon inverted grass-sod which has only recently been turned under, it will perhaps usually be found that the autumn is a better time for such seeding than the spring, for the reason that, at a season when rains are frequent, there will be less need of bringing the soil to a prime capillary condition than is the case in the spring, when the young plants are forced to depend in good measure upon the store of moisture which the land has accumulated during the winter.

It may be questioned whether the change from spring to autumn sowing in Massachusetts may not have been coincident with a general drying up of the soils, and the more frequent prevalence of summer droughts nowadays than formerly. Many parts of Maine are still well wooded, and much of the soil in that State is moist enough not to suffer, except in times of long-continued dry weather. The much greater abundance of weeds upon land that has long been cultivated, than on land that has recently been reclaimed from the forest, is doubtless in itself one reason why spring sowing is less esteemed in the older State than it used to be. But in many parts of Maine the land must be still, comparatively speaking, new, and free from weeds in somewhat the same measure.

On heavy clay-land that is not properly drained, it is said to be best to sow grass in the spring; for with such moist land the risk of burning off the young grass is small, and there is very great danger that the young grass-plants would be winter-killed, through "heaving" of the land, if the seeds were sown in autumn, though this difficulty could probably be met by top-dressing the newly seeded fields in the autumn with farmyard-manure.

It needs to be said, however, that the climate of Massachusetts is not particularly well suited for the growing of merchantable hay, excepting on low-lying land. It is evident enough, in view of the conditions and competitions to which our farmers are subjected, that many of the upland soils in this State are too poor and too dry to serve as really good mowing-land. In order to constant and assured success with grass it is essential that the land shall not suffer seriously from lack of moisture in the spring and early summer, and that droughts shall be rare at any season. This point may be emphasized by contrasting the insignificant quantity of grass-hay produced in the Southern States of this country with the abundant crops of the Northern and Eastern Atlantic States.

Gasparin has said of Europe that below the northernmost limit of wine-producing vineyards the risks, due to heat and drought, which attend the establishing of grass-fields are so great that it is the part of wisdom not to introduce grass into the regular rotations of crops, but to obtain this product from permanent low-lying meadows or by way of irrigation. Forage-crops, to supplement the meadow-grass, may be grown wherever they can be interpolated among other crops with the least inconvenience. It is under conditions such as these that beet-pulp and maize-ensilage

have been found to serve extremely well in France for feeding cattle.

Sowing of Grass with Grain.

It was customary, formerly, almost everywhere, to sow some kind of grain with the grass-seed, whereas nowadays, in the vicinity of Boston, grass is often sown by itself without any grain. The old plan was, on laying down land to grass in the autumn, to sow wheat or rye with the grass-seed; while, on seeding in the spring, barley, or spring wheat, or oats — sometimes spring rye — were used. It has been urged by some writers that, for spring sowing, either barley or spring wheat is to be preferred to oats, since "oats are sure to scald and kill the young grass if they lodge." In case barley lodges, it is less apt to smother the young grass than oats, and barley-grain will still fill out fairly well, even when the plants are lodged.

Beside the risk of lodging, it is thought by many New England farmers that oats interfere, in some unknown way, either with the germination of grass-seeds or with the growth of very young grass. It is probable, however, that these objections to oats apply more particularly to cases where it is desired to secure a crop of grain as well as a good catch of grass, and it may possibly be true that oats can safely be sown with grass in the spring, provided they are sown very thinly, and that the crop is mown early, and that the land is not too dry.

In any event, it is highly important in many localities — particularly on light soils in dry climates — when grass-seed is sown in the spring, that some kind of grain should be sown with it in order that the young grass shall be protected from weeds. It is a matter of experience that young grass is much better able to bear the shade cast by a thinly sown grain-crop than to withstand the shade and the dryness due to the presence of some kinds of weeds, and it is true, also, that grain growing together with young grass, sown in the spring, will hinder the progress of weeds which might otherwise smother the tender crop. In the autumn, on the other hand, the plants which spring from grain sown together with grass at that season, will help to hold a covering of snow upon the land during the winter, and so work to shield the grass from harm.

On land that is not insufferably foul, a single bushel of barley, or oats, or spring rye, sown broadcast to the acre immediately before the grass-seed, will speedily spring up, and afford shade

enough to hinder the germination and growth of many weeds without interfering with the young grass-plants to any serious extent. As for the risk that oats might do harm by lodging, that would be lessened or wholly done away with by taking the crop off the land rather early, i. e. by arranging to mow the oats for forage instead of allowing the grain to become ripe. It has been said of the drier parts of England, in regard to the spring sowing of grass on winter grain: "In a climate so dry as ours, where the rainfall averages only about 26 inches, we consider that the grain-crop is invaluable as a shade to the young seeds. With a more humid atmosphere, I should be inclined to sow down with rape." (Coleman.)

It is to be noted, however, that the need of shade is felt most strongly in the case of clover and sainfoin, and similar plants which open their cotyledons some little time before the throwing out of normal leaves. Where clover is grown, it is commonly advantageous to shade the young plants; the seed is usually sown upon grain, which shelters the first growth from hot sunshine. Some people in the more northerly States sow peas with their grass-seeds, and there are others who seed down in late summer and mix a small quantity of turnip-seed with the grass-seed. In that way they often get a good crop of turnips, without (as they claim) much injury to the young grass. In the vicinity of cities, where there is almost always a quick demand for long straw, rye is probably the best grain to sow with grass, though near Boston there is a noticeable tendency nowadays to sow rye by itself and grass-seed by itself, without any admixture. One motive, probably, is to get superexcellent straw, free from any admixture of grass-leaves.

Economy of growing Grain with Grass.

Undoubtedly the question of sowing grain with grass depends largely upon economical considerations. In spite of all that may justly be said of the grain's sheltering the young grass, and enabling it to "catch well," it would seem that on clean land, and in so far as the mere grass-crop is concerned, grain must usually do more harm than good when sown at the same time as the grass. But, on the other hand, if the farmer wishes to grow any grain on his farm, it will usually be found most convenient to get a crop of it with the grass, even if it be somewhat at the expense of the grass, since there will be a great saving of labor in preparing the

land, and a real economy of land; for when the grain is harvested, and sunlight is thereby let in upon the grass-plants, they are ready and waiting to grow up and yield a stubble-crop in the autumn. But a crop like this, well established upon the land, is a much more satisfactory result than a bare stubble-field that needs to be dealt with at a busy season; and in many cases as good a crop of hay may be expected next year as would be harvested in case no grain had been sown together with the grass-seed.

One advantage gained by growing grain and grass together is, that the supply of grain needed by a household can be got by cultivating only a small area of land. For example, if grass-seed was sown by itself, and oats were sown by themselves, as much as 18 acres of land in all might be needed each year. But the desired amount of oats can readily be got by cultivating no more than 12 acres devoted to the mixed crop.

The fact is simply that, when the farmers of New England grew their own grain, they sowed it with their grass-seed. Now that in many situations they find it cheaper to buy grain from the West, they not infrequently sow grass by itself. Or, stated in somewhat different words, the grass-crop has now become relatively so valuable in this section of the country that it often pays best to cultivate it solely for its own sake, and to exclude all methods of cropping or tillage that would be likely to interfere with the growth of the grass.

The sowing of grain with grass-seeds has, of course, a certain analogy with the sowing of a mixture of different kinds of grass-seeds, which is a practice very generally and very properly upheld. And, again, this idea of mixed seeds is somewhat akin to that article in the theory of the rotation of crops which depends upon the fact that different kinds of plants feed differently, both with regard to their power of taking substances from the soil, and as to the kinds of substances they take, or rather as to the times at which they take them. It is known that, in order to the full prosperity of any one particular plant, it must have a definite amount of standing room for its own behoof; but it is true, in many instances, that a plant can better bear to be crowded by plants of another kind or species than by its own immediate kith and kin.

The methods of growth of grass and clover, for example, are so unlike that the two plants can prosper side by side without greatly interfering with each other, and it is easy to believe that

a grass which, like orchard-grass, tends to grow in tufts, might well have some companion to grow with it in the interspaces; though in this case the associate would have to be able either to grow rapidly or to bear shade well, in order to escape being smothered at birth. One conspicuous merit of orchard-grass is that its rapid and powerful habit of growth prevents many kinds of weeds from growing among it. So, too, when red-top (Agrostis) is sown with timothy — as constantly happens in New England — so close a sod forms after a while that most weeds cannot grow upon the land so long as it is kept fertile.

In view of these facts, the question obtrudes itself: If timothy and red-top can each grow in the interspaces left by its neighbor, why may not oats grow there, or some other of those kinds of grasses which are commonly called grains? There is, indeed, small room to doubt that there are some advantages which tend to counterbalance the disadvantages of growing grass and grain together. Hence the conclusion that the growing of grain with grass is clearly admissible in many cases. One trouble may be that grain saps the surface-soil too much at the very time when the young grass-plants have most need of abundant food in order that they may become firmly rooted. Moreover, the grain-plants must steal water from the young grass, as well as food, when the two kinds of seeds are sown together. In humid climates, these difficulties are in some measure avoided by sowing the grass-seeds in the spring on winter grain that has already started to grow, as will be shown directly. On strong land, withal, where there is food and water enough for both the crops, the shelter afforded by the growing grain may be of real use to the young grass.

Where clover is sown in the autumn with wheat, it has often been noticed that the grain-crop may suffer somewhat during hot weather in the spring, because of the clover's taking water and food from the soil. The straw of such wheat is apt to dry slowly in the sheaves, because much clover is admixed with it, but it is particularly valuable as fodder on this account. These troubles are avoided by sowing the clover with or upon grain in the spring, and it is said that on the light, chalky soils of Norfolk, England, clovers, trefoil and sainfoin, but especially the latter, grow much better with wheat than with barley, since the wheat seldom lodges, and because its straw is stiffer and more upright, and readily admits the air. As the wheat has been sown some time before the

clover-seeds, the latter find a firm seed-bed, with enough fine loam to cover them without burying them too deeply, as happens often when they are sown on well pulverized barley-land.

It has been suggested that grass may be sown under Indian corn at the time of the last cultivation of this crop, in cases where flat cultivation has been practised, and where the land has been ploughed smooth for the corn at first. It is directed that the corn should be planted in straight rows, far enough apart to permit the cultivator to be run both ways between them. During the last cultivation, from 8 to 12 quarts of timothy to the acre may be harrowed in.

Grass-seeds must not be deeply buried.

As to the methods of sowing grass-seeds, experience teaches very emphatically that the seeds should not be buried deeply in the earth. Large-sized seeds, like peas, and maize, beans, lupines, and the like, may be buried pretty deeply without much harm. They contain a sufficient supply of nourishment to carry the sprout happily through a considerable layer of earth; but little seeds, like grass-seeds, have no such power, and there is great danger of losing them altogether if they are deeply covered.

It is true in general that, wherever seeds can be kept properly moistened, they should not be buried deeply, and this both because the seeds need air, and because of the risk of placing too many impediments in the way of the young shoot. The distance through which the shoot must pass in order to get above ground should be as short as possible, in order that the store of nourishment in the seed may not be wholly expended in the struggle with the layer of earth above the seed. Some of this store of nourishment is needed to establish the young plant firmly after it has reached the air.

One of the commonest ways of sowing white clover is to scatter the seed upon the last snow that falls in the spring, and leave it to take root upon the surface of the wet soil. Grass-seed is sometimes sown in the same way, and there seems to be little doubt that it would be a highly successful way, if the seed and the surface-soil could but be kept continuously moist while the seeds were germinating and the young plants were striking root. Clover is said to do specially well when sown on snow, provided it has not been threshed and winnowed, but left in the husks, so that moisture can the better be retained upon it. White clover is better suited

than grass for this service, since its creeping habit of growth permits it to take firm hold of the ground, and provide for its own support; whereas the young grass-plant, left lying upon the surface of a field, might be fretted and torn by winds. Nevertheless, the fact that grass-seeds can sometimes germinate and grow under the conditions above stated, points, of course, to the conclusion that, where the land is moist enough, there is small need of burying them deep in the earth. There are plenty of methodical experiments which show directly that deep burying is not only unnecessary, but hurtful to the last degree; and the same lesson is enforced by the enormous number of grass-seeds which farmers are in the habit of sowing upon the acre of land. Very little figuring is required to show that a large proportion of the seeds sown never come to any good, and the conclusion lies near at hand, that most of the missing individuals have been buried beyond all hope of recovery.

As was just now intimated, there would be little need of covering grass-seeds at all, if the young plants could but be shielded from winds at the moment of starting, and the surface of the ground be kept moist during the germination of the seeds, and until the young plants were firmly established. But in practice it is commonly necessary to give the seeds a slight covering of earth, in order that they may not become dry, and that the young plants may have such a hold upon the earth from the beginning that the wind cannot throw them about in every direction, and loosen their connections with the soil.

Methods of Sowing Grass.

In the vicinity of Boston, the common method of procedure is to bush in grass-seed, or to harrow it in very lightly, and then roll the surface of the land smooth. For the sake of crushing small lumps or clods of earth, which may have escaped the harrow, a light plank-drag or "smoother" may be drawn rapidly over the ground, best before strewing the grass-seed. If the land is rich and mellow, and in good capillary condition, so that a proper seed-bed can readily be prepared, neither bushing nor harrowing need be resorted to, for the roller will be all-sufficient for burying the seeds of such grasses as timothy and red-top, as well as for "firming" the soil. But if the land is crude and in poor condition, or if it be sandy or spongy, bushing or even harrowing will naturally be in order; and there are, of course, many fields,

too rough or stony for the roller to do good work, where the bush-harrow will need to be used. It is to be said, moreover, of orchard-grass, that its seeds need to be well covered, at the least on dry or loose soils, for it would appear that they do not absorb moisture so readily as some other kinds of grass-seeds.

When all the conditions are favorable, a good way of sowing timothy and red-top, here in New England, would be somewhat as follows: Starting with land in good tilth which has just been ploughed, it might be harrowed across to smooth it somewhat, then dressed with manure, and harrowed to work in the dung; then bushed again and again, if need be, or worked with a smoothing-harrow until a thoroughly smooth and even surface has been obtained. Upon this perfect seed-bed the grass-seed is sown at a quiet moment, as in the early morning. On small fields, it is well enough to resort to cross-sowing, i. e. to strew one-half the allotted quantity of seed each way, so that a particularly even distribution may be assured. The seed is then rolled in, as was said, or, if the roller be inadmissible, the seed may be covered in with a light bush. The main point is to smooth the land completely before the seed is strewn, so that none of it may be buried too deeply. It was for the purpose "of smoothing the surface before sowing, to prevent the seed from running down too low, and that of smoothing it afterwards as a preparation for the scythe," that the roller was formerly used in Norfolk Co., England. (Marshall.)

Practically, it seldom happens that the conditions are favorable for smoothing the land perfectly. In very many cases, and especially on light land, care has to be taken not to run the risk of drying out moisture from the soil unduly, by too much stirring. Oftener than not, when seeding land to grass, it will be best to spend the least possible amount of time in carrying out the operations which have to be performed between ploughing and the final rolling, simply for the sake of hindering the surface-soil from getting dry. The final rolling has the very great merit of bringing the seeds and the soil into intimate contact with each other. Thanks to the compaction of the soil, moisture can rise in it by capillary attraction to the very surface, and both the soil and the seeds are kept moist enough for the latter to sprout. Many little clods are crushed by the roller, and the soil and seeds are duly mixed. All this beside the merely mechanical advantage of making the field smooth, and fit for the passage of mowing-machines,

scythes and rakes. Of course the roller would not be used unless the land were sufficiently dry for it.

Importance of Rolling Grass-seeds.

It is to be insisted that on most light soils, and on those inadequately supplied with water, the action of the roller is all-important as a means of bringing moisture to the seeds and to the young plants. In some special cases it might even be well, on this account, to roll the land smooth before sowing grass-seeds, then to go over the field with a light harrow, as a preliminary to sowing, and finally to roll again. As the English farmers say, "grass-seeds require a fine, solid bed. . . . The great thing in laying land down is to have it clean and solid, with a fine tilth, otherwise the seeds cannot grow." It has been claimed that, in seeding land to grass or to grain, there may often be a certain advantage in using a fluted roller, rather than one which is plain, because the little ridges and hollows which are left by the fluted implement do actually, even when they are of trifling size, shelter and shade the first sprout of the tender plant which is commonly seen, in ordinary farm practice, to thrive best under the lee of a clod or stone or any little elevation. In Norway, the peasants have long been accustomed to crimp or corrugate the land in this way by nailing narrow strips of wood lengthwise upon the wooden roller, at distances of half an inch or so one from the other. (Laing.)

In the vicinity of Boston, when land is laid down to grass late in the autumn after abundant rains have fallen, there is comparatively little need of rolling after the seed has been sown, for the chances are that land charged with moisture at this season will remain moist. Probably there are many situations where no advantage would be gained by rolling grass or grain sown in the autumn, because the normal, natural rainfall would be competent to beat down the surface-soil to a sufficient degree of firmness. But it is evident that much of what has been said in the chapter on Rotations, of wheat's needing firm land, will apply with nearly equal force to grass. I have seen a mixture of timothy and red-top that had been sown late in May on a newly broken bog-meadow fail miserably in June, simply because a drought, which lasted but a few weeks, set in soon after the seeds had germinated, and made the surface-soil so loose and incoherent that the young grass-plants could not find any proper support, and because the loose earth had no power to suck up water from an abundant store of moisture

that lay no more than a foot or two beneath the surface of the soil.

In general, it is well to sow grass when the surface-soil is tolerably dry, though the land is well charged with water. A pleasant, quiet day, when rain is to be expected, is well suited for the purpose. On moderately dry land the seed can be covered in evenly, and can be rolled hard without injury to the tilth; and it is thought to be best that some time should elapse before rain falls, in order that the seeds may gradually absorb some moisture from the soil, and pass into a condition in which they can derive benefit from showers.

When grain is to be sown in conjunction with grass, the operations will need to be carried out in a somewhat different way from those just described, for the grain should be buried deeply enough to protect it from the ravages of birds, and to hinder those of mice and squirrels. Grass-seeds are so small that there is comparatively little risk of their suffering in this way, and after the roller has passed over them, it is not likely that they will be blown away.

In laying down land to grass with grain, it would be but natural to try to save as much trouble as possible. An inexperienced person might try to have the two kinds of seeds scattered simultaneously, and might then harrow the land deeply enough to cover the grain completely. But this method of procedure would be inadvisable, because the small amount of labor saved would not compensate for the grass-seed destroyed by the deep burying. An uneven stand of grass would be obtained, moreover, which would be uneconomical. It is not improbable that some part of the ill repute in which the plan of seeding grass with grain is now held really depends on the results of vicious practices which were employed formerly, without any just conception of their bearings and effects.

Nowadays the best farmers take care to avoid the risk of losing grass-seeds, when seeding down grass with grain, by sowing the grain by itself in the first place, and harrowing it in before they scatter the grass-seed. The operation remains very much as was just now described for grass alone, with the exception that the grain is sown before the field has been made completely smooth, so that the trouble of harrowing in the grain amounts to nothing, inasmuch as it represents one step in the process of smoothing the field for the grass.

Grass sown on Grain.

In the moist climate of Scotland a different method is adopted. Thus, upon farms in the immediate vicinity of Edinburgh, at the present day, "Grass-seeds are generally sown along with the barley-crop. When barley has been put down early, the grass-seeds are sown after it has come up well, because, if they are put in at the same time, the grass gets to be too profuse by harvest time, and causes great difficulty in securing the drying of the sheaves for the stack. In a favorable season sowing begins by the middle of April. Nowadays the seed is almost universally deposited by a drill 16 or 18 feet wide, and is covered in, either by a very light stroke of the harrow, or by a turn with the roller. The latter plan is mainly adopted, and is to be recommended because the nearer small seeds are to the surface the better." Another Scotch writer says: "Upon wheat, grass-seeds are not sown (in the spring) till the wheat-plant is strong enough to bear the heavy iron harrow, which is passed over the young wheat as soon as the grasses are sown, being succeeded in a few days by the land-roller. Where barley or oats have been sown, the grasses are generally sown immediately afterwards, some persons rolling the surface before sowing, then brushing the seed in with a brush prepared for the purpose, others sowing on the newly harrowed ground, and passing a lighter iron or wooden harrow over it, then rolling all down together. Others again merely roll the grasses in on the newly harrowed ground, but when this is done there is a risk that many of the seeds will not germinate."

In some parts of this country, also, a common method of sowing grass is to harrow winter wheat lightly in the spring, when it is about 2 inches high, or not more than 3 inches, to strew the grass-seed, and go over the field with a roller. This method has undoubted merit in localities where there is no great risk of drought, and the more particularly because the harrowing helps the growth of the grain. The idea is, that if wheat is harrowed in the spring, as soon as the ground is dry enough to bear a team, the crust upon the surface of the land is broken, and many small weeds are destroyed while the grain-plants get a start. It is said that on grain alone some farmers repeat the harrowing (using a smoothing-harrow) every week or two until the plants are a foot high.

There is, withal, another point to be considered. When grass

is sown on grain in the spring, the competition between the two crops must be much less keen than when grain and grass are sown together in the autumn. For when sown in the autumn, both crops will pass into the root-striking stage simultaneously, and in the same layer of soil, and it would seem that they must necessarily steal food from each other. But in the spring the grain-roots are already developed before the grass is sown, and they have in good part grown down out of the surface-soil, so that the young grass-plants find an empty room, comparatively speaking, and they have a fair chance to develop their system of roots without material hindrance at a time when the grain-plants are shooting.

Under these conditions, indeed, the grass-seeds may have an exceptionally good chance to germinate, since the shade cast by the grain tends to keep the surface of the ground cooler, damper, and less subject to sudden changes of weather, than it would be if no crop were growing upon the land, and the dew also which trickles down the grain-plants goes to help the young grass. Under the shadow of the grain-crop there will be much less risk of the young grass-plants burning off during any short spell of dry weather, than there would be if they were fully exposed to the sun and wind. But when once the grass-crop has become firmly established, then the shade of the grain must be injurious to it, and when the grass-roots have penetrated far enough to compete with those of the grain for water and for food, then each of the crops must do more or less injury to the other. Practically, however, the grain will be ripening off, or even be cut down and removed, before much harm can be done to it or by it in the competition.

Experiments with Buried Grass-seeds.

Mention may here be made of some of the details of methodical experiments which have been carried out with regard to the proper depth of burying grass-seeds. Hoffmann's experiments, cited in "How Crops Grow," p. 356, show that clover will not germinate, even under conditions that are in other respects favorable, when buried more than 3 or 4 inches. The grains, on the other hand, came up from a depth of 8 inches, and peas and corn from a depth of 10 inches. All the kinds of seeds tried by Hoffmann perished at 12 inches. Experiments by Lawson showed that grass-seeds need only a very light covering of earth. From nothing to one-quarter or half an inch he found to be the best depth. Some kinds

of seeds did not come up at all when buried a single inch, and few kinds came up at all when buried two inches.

A German experimenter, Jessen, who tried many kinds of grasses, has corroborated the results of Lawson. With timothy-seed, for example, he found that less than half the number of seeds sown half an inch deep came up either in loam or in sand, while all the seeds grew when they were sown 0.06 inch deep. Orchard-grass did even worse than timothy, i. e. the percentage of seeds lost by burying was greater. The general conclusion drawn from these experiments is, that grass and clover had best be buried no deeper than 0.03 in. on heavy land, and from 0.1 to 0.15 in. in sandy loam. In good medium loam they may be buried 0.05 in. in a moist season, and 0.1 in. in a dry time. The grains, on the contrary, should be buried about $\frac{1}{10}$ of an inch deep in heavy land, and $\frac{4}{10}$ of an inch deep in sandy loam. In loam of medium quality $\frac{1}{4}$ of an inch will be a good depth in moist weather, and $\frac{1}{3}$ of an inch in dry weather.

In some localities, the best depth for sowing grain will vary with the season; generally speaking, grain may be sown more deeply in early autumn than in the spring, since the low temperature of the soil in the spring is apt to hinder germination, or even to induce decay. Formerly, in some regions of light soils, grain was habitually ploughed in. Thus, in Norfolk County (England), toward the close of the last century, "The plough, with some few exceptions, was the only implement used in covering the seed" [wheat and barley]. (Marshall.)

Sometimes well to sow Grain deeply.

It is still true that, in very dry situations, deep seeding must always be in order. One of the practical rules enjoined upon Prussian farmers in 1756, by Frederic the Great, was as follows: "On light and sandy land it is highly advantageous not to sow rye on the surface, but to plough the seed under, in order that the deeply rooted young plants may the better bear frost and heat, and that the roots may not be laid bare by high winds." It has been said of some of our own Western States that autumnal droughts nowadays do less harm to wheat than they did formerly, since it is no longer customary there to sow winter wheat broadcast, but to drill it in to a depth of 3 inches. The young wheat-plants, springing from seeds thus thoroughly buried, can put to profit what moisture the soil does hold, and they are not apt to be disturbed to any serious extent by the wind.

It is not impossible that the rule of Frederic may have been a good one for the sandy plains of Prussia, though it is urged by recent German writers that, even on sandy land, rye should never be buried deeper than 2 or 3 inches, while on clayey soils it should be kept still nearer the surface. It has been said, indeed, that, in sowing rye, both the soil and the seed should be dry, and that the grain should merely be dusted in. Horsky, in seeking to improve the agriculture of Bohemia, dwelt forcibly on the disadvantages of the practice of sowing grain deeply. The usual practice of his neighborhood had been to sow from 2 to 4 inches deep, while he found, as the result of much experience, that on good, well tilled land, the best harvests were got when the grain was sown no deeper than half an inch. He noticed that at this depth the grain germinated freely, that the plants were vigorous, and that they tillered exceptionally well.

It has been shown, however, very clearly, by the following experiments of Hosaeus, that deep seeding may sometimes be advantageous. He operated in dry autumn weather on a light soil that dried out very easily. Parcels of wheat, each containing 100 grains, were sown at various depths on separate beds on the 5th of October, the day after a heavy rain, and the numbers of living plants were counted on the 18th and 25th of October, the 6th of November, and the 10th of December. From the 5th to the 19th of October, the weather was warm and clear, with cool nights and much dew; from the 19th to the 25th of October it was cold and rainy, and from the 25th of October to the 6th of November continuous dry weather. Thereafter the weather was changeable, with but little rain. The trials were in duplicate, as stated in the table. It appeared that for so light a soil in dry weather a depth of from ¾ of an inch to an inch was best for wheat. The shallow seeding of ⅓ inch gave somewhat less satisfactory results: —

Depth at which the Seeds were buried, in Centimetres. (1 cm. = 0.394 inch.)	Of 100 Seeds sown there were visible Plants on 18 Oct.	25 Oct.	6 Nov.	10 Dec.
1	45	70	73	73
	47	79	87	87
2	87	90	88	88
	87	96	98	98
3	88	93	93	89
	92	94	97	94
4	65	88	87	84
	74	92	95	89
7	34	82	82	81
	36	80	80	79

Tanner, in England, has urged that on loamy soils of medium character 1 inch is the best depth for sowing wheat, but that as the soil becomes lighter and more sandy, the depth may be increased to 1.5 or 2 inches. In a dry season, a less depth than 1 inch can seldom secure to the seed a proper supply of moisture, and a greater depth than 2 inches is to be deprecated on other accounts.

Heavy or Light Seeding?

The certainty of loss when grass-seeds are buried too deeply explains why it is that many excellent farmers are in the habit of sowing what seems to be a very large number of seeds upon the acre of land. In fact, the amount of seed that had best be sown is a question which has been much debated. There are many farmers who believe that the besetting sin of New England is to sow too lightly for grass; while others think that what is known as heavy seeding is mere folly and ignorance. As matters have stood hitherto, the advocates of heavy seeding have probably been more nearly right than their opponents, for it is plain that, if all the seeds that fall into cracks and holes in the land are to perish, as well as all those that happen to be buried under clods or the like, there must be a large allowance made for contingencies. How large this allowance commonly is in this vicinity may be seen by consulting C. L. Flint's "Treatise on Grasses." About 15 seeds to the square inch, as he computes, are commonly sown, while no more than 2 or 3 grass-plants are grown to the inch, and often not so many. In other words, it may be said that some 2,200 seeds to the square foot are commonly sown by the best farmers in Massachusetts, while ordinary pasture-sod contains only some 200 to 900 plants to the foot. Some very rich old pastures contain 1,000 plants to the foot, and as many as 1,800 plants to the foot have been found in the sod of a superlatively excellent irrigated meadow.

Some allowance has to be made, of course, for bad seed, and for the loss of young plants by droughts, and there is a real advantage, also, in having the stand of young grass thick enough to smother weeds, and to hinder weeds from starting; but the probabilities are that much more seed has been sown hitherto to the acre than would be proper if all the practices were perfect. Clearly, there should be less need of seeding heavily nowadays than there was formerly, since much greater pains are now taken

to smooth off the land before seeding it, and especially since the seeds are rolled in, or at the most lightly brushed, instead of being harrowed.

Moreover, it must never be forgotten that the infant plant, as well as the new-born fish, is subject to many calamities. The naturalist Darwin took pains to mark all the seedling weeds that came up on a plot three feet by two, which had been dug over and cleared so that there could be no choking from other plants, and he found that out of 357 little plants which came up, no less than 295 were destroyed, chiefly by slugs and insects. This result emphasizes the importance of liming land, as is often done in England, merely for the purpose of clearing it of such pests as these.

Instead of seeding heavily with one kind of grass, and seeking in this way to overcome all opposition, it would seem to be best to devote one's energies to preparing the land so thoroughly that it may hold a great store of moisture for the support of the crop, to careful seeding, and to the sowing together of two or more kinds of well-chosen seeds. There is little difficulty nowadays in obtaining from seedsmen as large a variety of grasses as anyone may wish to grow.

Winter-killing of Grass.

One great trouble in respect to grass in the climate of New England is to have the young crop "get a good catch," as the term is; that is to say, to have the young plants well started and firmly established. Against this desideratum, both the winter's cold and the summer's heat work very emphatically. There is, upon the one hand, the danger that the young grass which has been sown in the autumn or late summer will be "winter-killed, and, on the other, a nearly equal risk that the young grass will be "burnt off" by the sun's heat in times of drought, both in the autumn and in the summer.

In the vicinity of Boston, frost is specially apt to do harm to newly-seeded grass on low-lying, wet, peaty land, which is in process of reclamation, and particularly when the seed has been sown so late in the season that there has not been time enough for the growth of a mat or sod of plants on the surface-soil. Unless the texture of the crude bog-earth has been improved by an addition of gravel, or by being left bare during the preceding winter, so that it has been somewhat mellowed by the process of alternately freezing and thawing, raw bog-earth is liable to be

thrown up when it freezes into a condition of such extreme lightness and porosity that the roots of young grass-plants are left practically unattached to the soil, and must then necessarily perish.

During the very first of the autumn nights, when the air becomes cold enough to freeze water quickly, vast numbers of stalks or columns of ice, as thick as an ordinary lead-pencil, form at the surface of the wet bog-earth, and push or grow upward, often to a height of several inches, because of the continued freezing of new portions of water at and upon their bases. These stalks of ice stand side by side, almost as if they were growing plants, or, rather, like an exaggerated "pile" or "nap" upon cloth; and since bundles of the ice-stalks rise up together, they often lift considerable patches or layers of the soil so far away from their original position that they cannot regain it next day, when the ice is melted by the sun.

Where the conditions are specially favorable for the formation of this columnar ice, it is manifest that young grass-plants must be wholly incapable of withstanding several repetitions of the disorganizing process. Naturally enough, the excessive, or, so to say, fatal loosening of the soil, is not brought about all at once on the first night when the ground freezes. Irreparable harm may be done, however, by a succession of freezings and thaws whereby the cavities in the soil are filled repeatedly with the ice-masses which push the layers and particles of earth asunder.

Top-dressing hinders "Heaving."

In my own experience, I have found that this difficulty may be overcome, and an admirable stand of grass secured, even on bogs which have just been drained and ploughed, by top-dressing the young grass in the autumn, as soon as freezing weather has set in. My practice has been to spread farmyard-manure and night-soil on the wild bog in August, to plough under the manure, to harrow, and to sow a mixture of timothy and red-top. Finally, after the middle of November, the young grass is top-dressed with farmyard-manure, which mulches the land and seems to hinder or to prevent the formation of the peculiar columnar ice which is so harmful. In after years, i. e. when a firm sod of grass has once been established, and the bog-land has become consolidated and mellow, there is no longer any serious trouble from this cause, provided the land is well drained.

Wet, clayey soils are said to suffer from autumnal freezing much in the same way that unregenerated bog-land suffers; but of good upland loams it may justly be said, in many localities, that it is not so much the frost of autumn or the extreme cold of winter that kills young grass, as the freezing and thawing weather at the beginning of spring. Even when a winter is open and free from snow, young grass which was sown on upland fields in the autumn may be seen looking very well as late as February, and yet perish miserably, for the most part, between that time and April. It is generally recognized that steady cold weather does comparatively little harm to grass, even in the absence of snow; and that it is processes of repeated freezing and thawing that do mischief, by continually expanding and heaving up the surface-soil, and so stretching and tearing the grass-roots. This view is undoubtedly correct; but it is none the less true that extreme cold is of itself hurtful to some of the better kinds of grasses, especially when the plants are young. Upon exposed hillsides and ridges, where the winter winds hvae full sweep, some kinds of grasses are extremely liable to suffer from winter-killing, even when the weather is so cold that there is little or no chance for alternate freezing and thawing.

Winter-killing of Wheat.

According to Breymann — who has made observations in Germany as to the causes of the winter-killing of wheat — when land bare of snow freezes to a depth of 8 or 10 inches, and subsequently thaws to a depth of 3 or 4 inches, the wheat-crop may suffer severely when the ground freezes again to a depth of 2 or 2.5 inches; for after the land has once frozen, the main roots of the plant are held fixed and immovable in the lower layer of frozen earth, and the expansion of the soil at the surface, due to the second freezing, must lift the plants, and tend to tear them away from the roots, which are held firmly by the frozen ground below. It is seen, in fact, that many of the plants break at the weakest spot, viz., at the point where the young shoot came out of the grain at the time of germination.

A less common kind of winter-killing occurs when high winds blow for a long while during continuous cold weather, over bare, frozen ground. . Under these conditions the frost (i. e. the ice) may dry out completely from the surface of the land, and leave the soil as mere dust to be carried away by the wind. But when

the earth is removed in this way the wheat-plants have no longer any proper support, and they are continually shaken, bruised and torn by the wind, to their ultimate destruction.

On the other hand, the young grass may suffer severely on fields so flat that rain-water can stand in puddles upon the land after the earth has frozen. Here the chief trouble seems to be, that, when the water in the puddles freezes, the ice encloses the grass-stems and pulls them up, or tears them from the roots as it expands. Low and undrained land is probably worse in this respect than flat upland, chiefly, perhaps, because there is more time for this kind of action to occur upon it; for after the ground has once frozen in our climate, there is small chance for the soaking of water through it, no matter how good the drainage may be in spring or summer. But the winter may begin earlier on the lowland, and it may last there longer than on the upland.

Snow protects Grass.

When the ground is thoroughly covered with snow during the winter but little grass is winter-killed; and it was a common saying formerly in New England, that hay would naturally be abundant and cheap after a winter of frequent and enduring snows. Indeed, in most cold countries, a good depth of snow is thought to be highly beneficial to the farmer, by protecting grass and grain from severe spells of weather. "A snow year, a rich year," says the proverb.

Winter wheat can be grown farther to the north in New York and New England than in some of the Western States, because at the East the ground is fairly well protected in the winter by abundant and regular falls of snow, while at the West violent gales of wind are apt to sweep the flat prairie-land bare. Not only does the covering of snow hinder cold air from coming directly into contact with the soil and the crops, but, as Boussingault has shown, the snow acts as a screen to prevent the heat of the soil from being lost by way of radiation during the night.

In February, on a field that had been sown with wheat in the previous autumn, Boussingault placed the bulb of one thermometer beneath a layer of new-fallen snow that was 4 inches deep, in such manner that one side of the bulb touched the soil, and he placed the bulb of another thermometer on the surface of the snow, where a light fall of powdery snow during the night covered it to a depth of about one-tenth of an inch. A third thermometer was hung

in the air 40 feet from the ground, on the north side of a building, where it was shielded from excessive radiation. The following table gives the readings of the three thermometers: —

Date.	Hour.	The thermometer stood at °C. Under the snow.	On top of the snow.	In the air.	Remarks.
11 Feb.	5.30 P.M.	0°	−1.5°	+2.5°	Calm and a cloudless sky. The sun had set half an hour before the observation.
12 Feb.	7 A.M.	−3.5°	−12°	−3.5°	The sun had not yet reached the field. The night had been fine, calm and cloudless.
12 Feb.	5.30 P.M.	0°	−1.4°	+3.0°	After sunset.
13 Feb.	7 A.M.	−2°	−8.2°	−3.8°	Gray sky and slight wind.
13 Feb.	5.30 P.M.	0°	−1.0°	+4.5°	After sunset. Calm and clear.
14 Feb.	7 A.M.	0°	+0.5°	+2.0°	West wind and fine rain.

The sun shone brightly on the field of snow during the first three days of this experiment.

It is to be presumed that even a frozen soil thus shielded by snow may be melted to an appreciable extent, in many instances, by the action of the unfrozen ground-water beneath the frost. (See the paragraph relating to Frost in the Ground.) It will often be noticed in the spring that various hardy weeds begin to grow beneath a covering of soft snow sooner than they can grow when uncovered.

Snow better than Ice.

Snow is at its best when it lies light and loose, and evenly upon the land. After it has been exposed to long-continued cold, and particularly when solidified by processes of alternate thawing and freezing, snow shrinks in upon itself, and loses much of its protective power. The more nearly a bed of snow resembles ice, so much the deeper will the soil beneath it freeze in cold weather. A covering of ice is bad for grass, as may be seen, for example, almost any winter in Boston, in the yards on the shady (north) fronts of dwelling-houses. It will be noticed that in these yards the ground freezes deeply beneath the ice which covers the surface in late winter, and that the grass is often destroyed wellnigh completely. Undoubtedly this grass is exposed to a low degree of cold, but it would seem also that the thick layer of compact ice nust actually smother the plants by preventing any air from coming in contact with them. It is true, even of hibernating plants, that processes of life go on within them, and that the plants need to breathe in some oxygen, and expire some carbonic acid. Mayer and others have observed that the respiration of plants begins at temperatures even somewhat below that at which ice melts, i. e. respiration occurs at

temperatures decidedly lower than the lowest at which the growth of the plant is possible. It has been noticed in the mountainous parts of Europe, that fields of winter grain are apt to suffer injury when the land remains too long covered with very deep beds of snow; and it has been argued in this case also, that the injury to the crop is caused by the lack of light and air.

In any event, ice, though commonly accounted a bad conductor of heat, can hardly be compared with snow in this particular; for, as it occurs in the fields, the loose, light-lying snow encloses a large amount of air in its interstices, and this air, being an excellent non-conductor of heat, tends to prevent the escape of heat from the soil, and greatly hinders the penetration of frost. The ground usually freezes to a much greater depth in snowless winters than in those when snow abounds. It has been reported of the region about Lake Superior, where more or less snow falls almost every day during the winter, and the accumulation of it is enormous, that the first fall usually occurs before the ground has frozen, so that the soil is protected from frost to a remarkable degree. Vegetables, such as turnips and potatoes, that have been left standing in the ground there may be dug any time after the cold weather has set in, by first removing the snow which covers them; and it is said to be a common occurrence there for such crops to renew themselves without successive plantings.

It has been said in Germany that wheat is apt to be smothered, from want of air and light, when deep snows fall upon it before the ground has frozen and remain lying upon the land. Special harm is done when a thick crust of ice forms at the surface of such unseasonable snow. One advantage to be credited to snow which falls late in the spring is, that the coat of snow may shield the land somewhat from the beating action of rain, while the soil will be moistened very thoroughly and gradually when the snow melts.

Spring Rolling of Grass-fields.

It is commonly taught that it is well, where young grass has suffered from frost during the winter, to go over the field with a roller in the spring, for the purpose of firming the land, and of crowding back into the soil the roots that have been torn or loosened by the expansion of the ice. The practice is a good one, provided the work can be done at an appropriate moment, when the ground has become dry enough to bear the horse, and to

let the roller pass without sticking or clinging to it, and before the roots have been exposed to the wind and sun. Often, it might be well, when such land is to be rolled in the spring, to scatter beforehand a little fresh seed. An incidental advantage to be gained by rolling the measurably bare land is, that the loose pebbles which have been thrown out upon the surface will be pressed into the soil, out of the way of the scythe or the knives of the mowing-machine.

In England, when land is laid down for pasture, it is customary to drag a roller over the young grass when once it is fairly established, i. e. when the plants are 3 or 4 inches high. It is true, in general, that, on most soils, grass-land may be improved by rolling it frequently, particularly in the spring. The habit of growth of many kinds of grass is such that new leaves and sprouts spring from the crown of the roots of the old plants, so that the new crop is apt to be less intimately connected with the soil than its predecessor was, unless, indeed, it has been subjected to the trampling of cattle or to compression by the roller. In the absence of compressing influences, the grass-plants may finally come to have no proper foothold on the earth. Thus, in order to maintain a firm sward upon lawns, it is customary to roll the sod very often, not only in the spring, to correct the looseness and sponginess of the old sod, but during the summer whenever the grass has been clipped.

Burning off of Grass.

As for the opposite risk of "burning off," that may occur in summer in times of drought, or in case the seed is sown in the autumn, it may occur then also if there has been a drought during the summer, or if a specially dry spell of weather should happen to follow the sowing. If grass is sown in August upon a dry field, there is risk of the seeds sprouting by virtue of moisture obtained from dews, or from an occasional light rain, and that the young plants will die afterwards in case there should come a few days of hot, dry weather before the ground has been thoroughly soaked by the autumnal rains. It is for this reason that, in dry seasons, farmers near Boston are loath to sow grass-seed in August, except on mellow, low-lying land, i. e. on land well provided with moisture. On the uplands, they like to play a sure game by keeping within the influence of the "line storm," as they say (September 21), although it is a well recognized fact that, were it not for

this risk of drought, it would be far better to get the grass-seed started in August than to wait until September, since the older the plants are when winter sets in, so much the better will they withstand the rigors of that season. One merit, by the way, of thick seeding is, that when many young plants are burned off by drought in early autumn, there may still be left in the soil an abundant supply of seeds that were slow to germinate, which will finally sprout and stock the field, when the land comes to be thoroughly moistened.

Power of Young Plants to resist Drought.

Something may be judged, perhaps, of the power of very young grass to withstand drought, from the experiments of De Saussure, which have shown that many plants have a surprising power of recuperation when overtaken by drought during the act of germination. As a matter of course, it must often happen that a light rain, falling soon after grain has been sown, will cause the seeds to sprout, and that the act of germination will be arrested when the ground again becomes dry. But, curiously enough, it is true of many kinds of seeds, that the acts of sprouting and drying may be several times repeated without ruining the crop.

De Saussure took well preserved seeds of various kinds which were one year old, and caused them to germinate, either on moistened sponges or on blotting-paper, and he made experiments at 3 different stages of development, viz. as nearly as might be, 1. At the moment when the radicle had begun to appear, and was not yet half as long as the seed ; 2. When the radicle was fully as long as the seed, and 3, When the fully-developed plumule began to appear outside of its envelopes. Seeds selected at each of these three stages of development were kiln-dried by being kept for several days in an oven heated to 96° F., a temperature regarded as the highest ordinarily experienced at Geneva, in the shade.

The baked seeds were then kept in a dry room at about 60° F., during terms ranging from one to several months, when they were again placed on moistened sponge or paper, and allowed to germinate anew. It appeared that, under the conditions above set forth, the seeds of wheat, rye, barley, maize, vetches, lentils, cresses, hemp, cabbage, mustard, lettuce and buckwheat preserved their power of vegetating after having been kept in a dry place during 2 or 3 months. None of the seeds examined were viable after the lapse of a year, though those of wheat, in stages Nos. I and II were recalled to life after having lain dry for six months and a half. Many kinds of seeds, however, exhibited no such power of recuperation after they had been dried while germinating and subsequently left for some time in a dry place ; among them may be mentioned peas, beans, parsnips, poppies, asters, portulaca and campanula. Some of the details of De Saussure's observations are given in the following table :—

The Germination of Seeds of	Began, in the case of normal seeds, in days at ° F.	No. of weeks the seeds lay dry, after having been baked.	No. of days that elapsed before the seeds sprouted anew in the case of No. I.	No. II.	No. III,
Wheat	2, at 59 to 63°	10	2 to 2.5	5	7
Rye	2, "	8	2 to 2.5	. . .	4 to 5
Barley	3, "	8	8	8	endless
Oats (husked) . .	2, at 68°	10	2	endless	"
Maize	8, at 68°	8	12	"	"
Buckwheat . . .	4, at 59 to 61°	8	6	14	"
Vetch	2, "	9	2	14	16
Lentil	4, at 59°	8	4	6	endless
Cress	2.5 at 59°	9	5	5+	"
Cabbage	4, at 59°	8	4	14	"
Mustard	1, at 70°	10	2	4	—
Hemp	4, at 59°	8	4	endless	endless
Lettuce	2, at 63 to 65°	10	6	"	"
White Clover . .	1, at 79°	10	8	"	"

It will be noticed that comparatively few of the seeds taken in the third stage of development grew again after the act of drying. In the case of wheat, for example, only a small proportion of the seeds of No. III recovered, and special care and pains had to be taken in order that any of them should be saved. The growth of the young plants in this case was extremely slow; they were hardly two inches tall at the end of a fortnight, while the plants of No. II grew 3 inches in this space of time. It was observed none the less — of wheat, rye, peas, and buckwheat — that when the seeds had once recovered themselves, the very young plants were able to bear new alternations of dessication and vegetation without perishing.

The plumules of seeds dried during germination, those of wheat, for example, remain practically intact, and continue their growth when moistened, but the radicles which the seeds have thrown out are destroyed by the drying. Hence the vigor of the seed is in so far impaired, for new rootlets have to be formed whenever germination is renewed. It may be said, also, that the germinative force of the dried seeds was weaker somewhat in proportion as the act of germination was more advanced at the moment of drying, and that on this account a longer time was required for the germination of sprouted and dried seeds than was sufficient in the case of fresh seeds. It was determined that most of the seeds No. I had lost 2 or 3% of their weight during this so to say preliminary stage of germination, though in some cases losses of 7 or 8% were noted. One trouble with the seeds No. III was their liability to be destroyed by decay during the long time required by the germs to recover themselves. This difficulty was encountered in the case of buckwheat, for example, and that of oats in the husk, and was still more thoroughly marked in those kinds of seeds which are known to be apt to putrefy, such as peas and beans.

In other experiments, the dried, sprouted seeds were exposed to a temperature of 158° F., which was regarded as the highest temperature that any soil at Geneva could possibly attain in direct sunshine at midsummer, and it was found that while seeds No. II were destroyed in every instance by this treatment, seeds No. I of wheat, rye, cabbage, buckwheat and vetch recovered and grew again, al-

though more slowly than the seeds which had not been so strongly heated. But seeds No. I of barley, hemp and peas did not recover after having been heated to 150 à 158°. It is to be remarked that the seeds which did recover were already dry when they were heated, and that De Saussure expressed his conviction that none of them could have recovered if they had been exposed to so strong a heat without having been slowly dried previously. He says, however, that he has repeatedly noticed that seeds No. I are not destroyed by direct sunlight at temperatures produced by it on ordinary soils. Spallanzani had observed long previously that dried germinated seeds could be exposed for two minutes to a temperature of 167° F. without losing their vitality. He tried, also, the experiment of putting the radicles of sprouted seeds, which had not been dried, into water as hot as 145°, or even 156° F., and found that they were not killed by an exposure of two minutes.

Nowoczec also caused seeds to germinate on moistened flannel, and when their roots and sprout had attained a length of 1 cm. (= 0.394 inch) he dried out the flannel together with the young plants at a temperature of from 60° to 68° F. The flannel was then moistened anew and again dried, and the processes of moistening and drying were repeated as long as any of the plants were alive. His results are given in the following table, whence it appears in full corroboration of De Saussure's much earlier work, that germinating seeds of wheat, barley and rye have an extraordinary power of resisting drought. It was seen that the rootlets died completely every time the young plants were dried, and that new roots were developed when the plants were again moistened. The leaf-shoots also dried off at their points, but the internal organs remained alive, and developed new parts on being moistened, even when the shoots had attained a length of ¾ of an inch or an inch. Oily seeds, and those of peas and clover, exhibited very much less power of resisting drought than those of the grains proper.

On Oct. 24 there Were laid out to germinate 100 seeds of	Up to Oct. 31 there had germinated	No. of plants that grew again after each Drying:— 2d Drying to Nov. 10.	3d Drying to Nov. 27.	4th Drying to Dec. 9.	5th drying to Dec. 25.	6th Drying to Jan. 5.	7th Drying to Jan. 13
Wheat . . .	75	70	57	31	25	10	1
Barley . . .	85	78	74	40	33	17	4
Oats	90	83	77	62	40	27	8
Maize	98	96	66	14	3	0	0
Rape	85	55	27	17	1	0	0
Flax	88	78	30	9	0	0	0
Red clover . .	85	41	10	3	0	0	0
Peas	87	38	3	0	0	0	0

One trouble with seeds so small as those of grass is that the absolute quantity of nutriment within them is not large enough to long withstand the drain and waste which must necessarily occur when the young sprout has to struggle for its life.

Even the grass of old fields may be partially killed off in midsummer by excessive heat, particularly at those spots where the larvæ

of the June-bug or other enemies have been devouring its roots. One way of lessening this risk manifestly is to abstain from mowing the fields too closely, so that the grass shall not all be cut off close to the roots. If a joint or two of the stem and some leaves are left, for the plants to breathe and feed by, the grass will naturally stand a somewhat better chance of resisting hardships than if the plants had been shorn off close to the earth. For in spite of the fact that such lower leaves might be old and feeble, they could still do something towards supporting the roots at a critical period. So, too, if grass is mown when tolerably young and vigorous, and not yet dead ripe, there will be comparatively little risk of the roots being killed by heat.

In case the grasses grown are of kinds fit to be irrigated, one sure way of giving the plants a new start after mowing would be to drench the land with water immediately after the hay-crop has been carried off from it. When grass-lands come to be irrigated more commonly than they are now in this country there will be much less trouble on account of the sun's heat. There are many upland hay-fields and pastures in New England where irrigation is the one thing needful to enable grass to withstand the dry summers of the locality; and although this method of husbandry may not yet be economically practicable — exceptions being made for special instances where circumstances are particularly favorable— it may still be said of the method that the American people will have to come to come to it, sooner or later, and the remark will apply even more forcibly to the Southern and Middle States than to those at the North. There is small reason why permanent water-meadows should not be established in many parts of the South, from which grass could be cut pretty much all the year round, as has been done in Lombardy time out of mind.

Grass needs Moisture.

It is a well known fact that grass grows best in rainy countries, and, as Lawes and Gilbert have urged, several reasons concur to make the hay-crop more sensitive to fluctuations in the amount of rain falling during the season of active growth than wheat is when growing under like conditions as to soil and manure. Wheat and rye, sown in the autumn, secure possession of a great bulk of soil by their underground feeders, and make ready to avail themselves of the supplies of food and moisture in the land, even to a considerable depth. In England, indeed, the wheat-plant continues to

make root, more or less according to season and manure, throughout the winter months, and the experience of English farmers teaches that, as compared with hay, wheat is not only less dependent on the rain which falls in late spring and early summer, but more on a relatively high degree of temperature during this period.

"The perennial, or biennial, character of most of the plants in an old hay-field would seem, at first sight, to give the grass a great advantage over the grain-crops. But observation shows that, although the superficial layers of the soil may be more thoroughly penetrated by the roots of the grasses than by those of wheat or barley, yet it is only a very few of the grasses, encouraged to great predominance under special conditions, that seem to get anything like the same possession of the lower layers of the soil as the two grain-crops."

It is remarkable, in the experiments of Lawes and Gilbert, notwithstanding the great fluctuations in the amounts of produce of each of the three crops from year to year, according to season, that, when the average is taken over a considerable number of years, hay (excluding aftermath), wheat and barley are seen to yield, without manure, almost identically the same average weight of produce per acre per annum. But in a year of extreme drought (1870) the deficiency, on unmanured land, of the hay-crop was 1,747 lb. to the acre, that of the barley-crop (grain and straw) was 964 lb., and that of the wheat-crop was only 396 lb. In other words, while the yield of hay was reduced by the drought of 1870 to the extent of nearly three-fourths, as compared with an average crop, the deficiency in the case of barley was hardly two-fifths, and in the case of wheat about one-sixth.

Top-dressing Grass-fields.

Marked differences are noticeable in different localities both as to the prevalence of the system of top-dressing and as to the times and seasons at which the dressings are applied. Thus, in the southern counties of England, it was an old practice to top-dress the mowing-fields at Christmas, while in Yorkshire the manure was applied as soon as possible after the fields had been mown. Hunter, who experimented upon this question at the middle of the last century, was led to "venture to say that it is better to manure when there is some life in the grass than at a time when all vegetation is stopt. . . . Could we always be sure of a shower of rain within a few days after laying on the manure, the midsummer method would incontestibly be the best; but even without that certainty, I find it better [for England] than the other."

There is one marked advantage in applying manure on moist

land after the hay-harvest, in that grass-seeds which have been shed upon the land are encouraged to germinate and grow, and so to restock the field. In many situations, where the land is not too dry, timothy-fields could probably be made to endure in this way during a longer term of years than is usual. The practice might well be a profitable one on many stiff soils, particularly on moist clays which cannot readily be tilled.

In certain districts in Devonshire, tenants were sometimes required, by the terms of their leases, to apply large quantities of manure to land that was kept permanently in pasture; as much as 20 or 30 two-horse loads to the acre. Some of the early agricultural writers were of the opinion that "the time to spread the manure is the autumn, before the rains have soaked the ground and rendered it too soft to cart on." They were of opinion that the manure should be thoroughly rotted and evenly spread. More recent English writers have urged that 10 or 12 tons of manure from stall-fed cattle, reduced so far as not to appear strawy, would be a fair dressing for an acre of grass-land. They would apply it in showery weather at the end of September or in October.

Grass thrives when the Nights are Cold.

In the vicinity of Boston there is a decided gain in top-dressing old grass-lands early in the autumn, as soon as the nights have become cold enough to check the growth of such weeds as need continuous hot weather for their free development. For in case the autumn is fairly moist the manure will cause the grass to grow freely, in spite of the cool night air, at the very time when the growth of the weeds is checked. In this way good grasses may be put into full possession of the land, while their competitors are smothered. This remark will apply, of course, to all northern climates, and it is a fact that several American writers have maintained that one good way of getting profit from mowing-fields on cold, clayey soils, is to top-dress them in the autumn, before the land has been too much softened by rain.

Some farmers have argued that it pays better to manure good grass-land than poor. They hold that the limit to which manure can be profitably used is indicated by the lodging of the grass before it is ripe, in which event it is liable to rot at the bottom. The plan of thus manuring rather heavily is doubtless well suited for fields of timothy; but in England, where finer kinds of hay are

preferred, it has been urged that grass-land should be manured little and often, since heavy dressings of dung promote the growth of coarse, rank grass. It is manifest that a safe course would be to apply the manure in moderate quantities, in order to keep the grass from running out, or for the sake of bringing up fields in situations where cultivation would be inconvenient. One merit of heavy dressings is, that many kinds of weeds may be choked with certainty. For example, it is a common opinion in New England that the ox-eye daisy seldom thrives in fields where the crop of hay amounts to as much as a ton and a half to the acre.

Top-dressing of Newly-sown Grass.

Here in Massachusetts excellent results may be obtained by top-dressing in the autumn — just before the ground freezes — fields of young grass which have been laid down no longer than a month or two. This method of procedure, though applicable to all grass-fields, is specially adapted, as has been said, to low-lying meadows, where it prevents the young grass from being "hove out" by frost; and it is perhaps best, in such situations, to use a somewhat strawy manure, which will serve to mulch the land as well as to fertilize it.

The top-dressing of newly-seeded lawns, also, just before the ground freezes, is a highly commendable practice. Indeed, it might be cordially recommended for all newly-seeded grass-land, were it not for the cost of the labor and the manure. Young clover, also, which has come from the spring sowing of clover-seed on wheat, may often need to be helped forward by putting upon the wheat-stubble a light top-dressing of barnyard-manure; but in this case the manure should be fine and friable, lest it should smother the tender clover-plants, and it may best be distributed with a manure-spreader just before a shower of rain.

Composts are Good for Grass.

It has been noticed, in England, that coal-ashes and cinders have a very marked effect in improving pastures on clayey soils, the inference being that, by their mechanical action, the ashes prevent the land from getting hide-bound. Similar results have been obtained on clays by the use of sand, brick-dust and road-scrapings, and most farmers are agreed that mere dirt is useful as a top-dressing, even in cases where it is hardly to be supposed that it can have any direct action as a manure, and they are thus naturally led to look with much favor upon peat composts.

There is little doubt that a thin sprinkling of loam, laid on very early in the spring, or in the autumn, might have an important influence for good, both as a mulch to hold moisture at the surface of the land and as a means of covering roots which have been torn by the winter's frost, or which would be so torn if they had not been thus covered. Moreover, the habit of some kinds of grasses of growing from the crown of the roots of the previous year, tends gradually to lift the grass away from the soil, and to leave the sod loose and spongy. Hence there must usually be a certain advantage in using stable-manure or compost for grass-lands instead of mineral fertilizers. Peat-composts, fermented with dung, are clearly indicated for this purpose.

Weeds do little Harm on Rich Grass-land.

If the land has been well laid down within a few years, and is still in good heart, many of the seeds of weeds which may be contained in the manure will do comparatively little harm upon the grass-land, for most kinds of weeds will come to nothing when smothered by vigorous grass and cut down with the latter when it is mown. It is true that manures differ widely in respect to the seeds of weeds. Cow-manure, especially that which has undergone wet fermentation in the deep pits of continental Europe, may perhaps be comparatively free from weed-seeds, while horse-manure which has not been worked over by swine may be highly charged with them.

The seeds of the ox-eye daisy, for example, appear not to be digested by horses, and multitudes of these seeds are carried to the land in the horse-manure which is hauled out from the stables of American cities. Another seed which is not readily digested by horses or injured by the ordinary fermentations of horse-manure, is that of the common carrot, which is apt to run wild in old hay-fields. These weeds may be destroyed, of course, by growing hoed crops upon the land, and freely using the cultivator and the hoe. But it is to be insisted, yet again, that manure, even very highly charged with weed-seeds, may still be used for renovating grass-fields on cold, low-lying land, if it is spread upon the old sod and ploughed under deeply, in preparation for a new seeding; for so long as the weed-seeds are kept away from the air they will not germinate, and on wet land a very considerable proportion of them will soon decay.

It is noteworthy that, in the region near Portsmouth, N. H.,

where sea-weed is the chief manure, the farmers are accustomed so to dispose of their stable-manure that the weed-seeds in it can do but little harm, and to use the sea-weeds in such manner that clean culture is ensured. The sea-manure cannot by any possibility introduce weeds, although it may perchance favor the growth of some species. It is evident that peat-composts made with ashes or potashes, or with lime, or a mixture of lime and muriate of potash, might be harrowed into the surface-soil where weedy-manure has been buried, and so be made to serve, instead of the sea-weeds, to start the grass-seeds; or these composts might be applied directly for top-dressing grass-fields.

A compost much esteemed in England for destroying moss in old pastures, is made by mixing 2 cartloads of quicklime with 8 cartloads of good, light loam, and turning the mixture several times in order that the lime shall be completely slaked and commingled with the earth. The quantities here given are said to be enough for an acre of land. After spreading the compost in the spring the sod should be well harrowed; and it is customary to take a crop of hay from the land before allowing animals to graze upon it.

Top-dressings should be Early.

In applying manure to grass-fields in northern countries, it will assuredly be well to do so tolerably early, whether it be done in the spring or in the autumn. Just as in the spring no prudent person would wait until the ground was soft enough to be poached by the feet of animals and rutted by cart-wheels, so in the autumn the application of manure should not be delayed until the beginning of winter, when the ground has frozen so hard that little of the goodness of the manure can soak into it. The chief point to be considered is, that the soluble matters of the manure may be carried into the soil by rain as speedily as possible; and it is to be remembered that, in lower New England, comparatively little of this leaching action can be counted upon after the heavy rains of the spring have ceased to fall, until the thunder-showers of summer set in.

Hence, upon dry upland mowing-fields, it might well be argued that top-dressings should either be applied early in the spring, as has been said, or not too late in the autumn. It has been claimed here in New England, that excellent crops of grass have been obtained by spreading 10 or 12 two-horse loads of manure on mow-

ing-fields in February, and that it is easy in this way to get 3.5 tons of hay to the acre, in a good season, instead of 2 tons. But it is noticeable in the vicinity of Boston, where top-dressings are often applied to lawns and garden-borders after the ground has frozen, that a large proportion of the manure is apt to be washed off bodily into brooks or ponds; to say nothing of the fact that what manure is left upon the land is leached by rains in such manner that many of its soluble constituents are carried away. There will be some risk, of course, if the land be top-dressed very early in the autumn, that too rank a growth of aftermath may be excited, and although a tolerably thick bed of dead grass upon a field may be an excellent protection against winter-killing, it is objectionable, in that it affords shelter for mice which eat the grass-roots, and that the land is encumbered by it next spring.

Autumnal Top-dressings are the Best.

For New England, it would seem to be plain that the autumn must ordinarily be the best season for top-dressing mowing-fields, for it is desirable that the manure should be rained upon soon after it has been spread, and that it should be applied long enough before the time when the next crop is to grow, that the soil may become thoroughly saturated with fertilizing matters, though this consideration will naturally be of more importance in some situations than in others, according to the character of the soil, and to its relations with ground-water.

Much must depend upon the season, also, and there are farmers who claim to have noticed, on top-dressing their grass-fields in the spring, that not the first crop but only the aftermath has shown the full effect of the manure. It is true, also, as a general rule, that it would be well to encourage a full growth of the roots of any grass-crop in the autumn of the year before that in which the crop is to be mown; and it is assuredly best not to apply manure to grass which is soon to be mown or pastured, because the rank flavor of such grass would make it in some degree unpalatable to animals. This objection would apply particularly to the case in which grass-fields are top-dressed immediately after the hay-harvest, for the abundant growth of rowen, or of "fall feed," obtained in this way could hardly be so well relished by animals as grass which had not just been manured.

Top-dressing not practised in Dry Regions.

It is noticeable that top-dressing is not held in esteem in coun-

tries where the rains are not advantageously distributed. According to Gasparin, top-dressing is rarely practised at the south of France, excepting upon meadows that are irrigated. I have myself witnessed, near Boston, several instances in which hardly any perceptible effect was produced by liberal top-dressings of cow-dung applied — sometimes in the winter and sometimes in midsummer — to old fields and pastures, because dry weather happened to set in soon after the application of the manure. It was manifest on these fields that by far the larger part of the useful constituents of the manure had been dissipated without ever having done the land or the crop any appreciable good. It is evident, indeed, from what has been said in Chapter XXI of the liability that the fertilizing matters in unburied manure may be lost, that top-dressing, in spite of its convenience as regards grass, is far enough from being an ideal method of applying manure. On dry fields and in dry climates, the farmer who practises top-dressing will necessarily run no little risk of wasting a good part of his manure, unless he should be favored by seasonable rains.

Old New-England Practice.

Of New England, Ryder wrote, long ago, as follows: "As to the time of year when manure ought to be applied to grass-grounds, it must be varied by circumstances. It may be done as soon after mowing as is convenient, and, if in the spring, not later than March. If the land is naturally wet, so that in the spring months it is saturated with water, the manure should be applied as soon as possible after the grass is mowed. By so doing, the rain in the dry part of the season soaks into the ground, and carries with it the strength of the manure, which is thus secured for the benefit of the land. If on such land manure be put on late in autumn or winter, the rains float off a great part of its substance, and the effect is comparatively trifling.

"Another case where the manure should be applied in summer is where the land is so poor that the grass is weak and thin. Here the manure should be applied immediately after mowing, so that the grass may have time to thicken up in the autumn, for the year following. The greatest effect from the manure will then be observed in the first crop of grass, while, if put on late, the greatest effect will not be observed until the second crop is obtained.

"Early spreading is generally the best on any meadow-land. I prefer unfermented stable-manure, with the litter undecomposed, to the same manure in a rotten state; and hot, dry weather in summer forms no objection with me to applying the manure immediately. In the dryest weather, the grass will soon spring up through the manure, when it will not grow at all on the parts adjacent. The manure should be spread very evenly over the ground, and if it be long manure it should be shaken fine off the fork. Few hired men are willing to perform the work aright."

Sheep for Top-dressing Grass.

In Europe, mowing-fields and lawns have sometimes been top-dressed very effectively by penning upon the grass a flock of sheep in early autumn. Arthur Young describes an instance where the movable fences used consisted of poles 12 feet long and 5 inches in diameter, stuck through with perpendiculars, and having at each end two longer pieces to rest on, in the form of a cross. These frames were readily moved from place to place on occasion, and set up so as to keep the sheep in any desired place. It is said that no other method of manuring grass is equal to this, and that the expense is but small. The sheep act, of course, incidentally to gnaw down and discourage many kinds of weeds. In the damp climate of Ireland, in particular, run-out mowing-fields that could not be broken up conveniently have occasionally been teathed with a large flock of sheep. Feeding-troughs, charged daily with oil-cake, are placed in a row upon the field, and shifted from place to place at regular intervals, until the entire field has been gone over as many times as may seem to be necessary.

An Objection to Top-dressing.

Against the general idea of top-dressing mowing-fields may be urged the fact that the manner in which grass grows does not permit it to make use of any very great depth of soil unless manure has been thoroughly incorporated with that soil. When adequately moistened, there is a natural tendency, on the part of the running roots of many kinds of grasses, to grow constantly near the surface of the soil, as they become covered up either by the decay of the sod or by top-dressings. Thus, new rootlets are continually thrown out at higher levels than those occupied by the older roots, while deep-lying rootlets may tend to die out. Hence it happens that thick, well-formed old sods of any given kind of grass are found to have pretty much one and the same thickness on different fields, and that this thickness seems to be in some sort essential for the prosperity of the grass. It is well known that this layer of roots and grass-plants holds a great store of accumulated fertility, which may be made to support other crops on breaking up the land.

The foregoing applies, of course, more particularly to old fields and to permanent grass-fields than to those which have recently been laid down; but the suggestion goes to show that top-dressing is to be commended rather as a means of hindering good grass-fields from deterioration, especially on moist land, than as a device for re-establishing worn-out fields. As bearing upon this idea, Aitken recommends that pains should be taken to incorporate the manure with the soil, and to bring it into actual contact with the grass-roots. He says: "Where grass is top-dressed with anything but perfectly soluble manures, it is advantageous to bring them under the surface by some mechanical process, such as rolling with a heavy Cambridge

roller, or similar instrument, that will not only press but cut the sod. Harrowing, succeeded by rolling or the heavy treading of fat cattle, or some such mechanical treatment, which will cause the manure to sink into the grass, is necessary to make the top-dressing exert its most beneficial effect."

Waste of Unburied Manure.

It has often been urged by agricultural writers that manure left lying out upon the surface of the soil is specially liable to suffer loss through hurtful fermentations, though this source of waste is probably much more serious on dry fields than it would be on a well moistened meadow. Gasparin, in speaking of the South of France, has said that when well moistened grass-fields are top-dressed every third year with manure containing 224 lb. of nitrogen to the acre, there is obtained in the course of the three years an increase of hay amounting to 6 tons, and containing 170 lb. of nitrogen, which amounts to about three-quarters of that applied in the manure. But, as has been stated in Chapter XIV, experience with many other plants beside grass goes to show that it is not at all an easy matter to recover, in the increase of crop, all the nitrogen that was contained in the manure.

In another experiment, cited by Gasparin, a grass-field which yielded when unmanured 1,760 lb. of hay, gave 6,160 lb. of hay on being top-dressed with 13 tons of manure that contained 106 lb. of nitrogen. Inasmuch as the 4,400 lb. increase of hay contained 62 lb. of nitrogen, it appears that but little more than one-half the nitrogen applied was recovered in the increase of crop. It is not surprising that this result should be reached, in view of the well known fact that an old grass-field represents a considerable stock of accumulated fertility, which may be put to use by the crops grown upon the land after the sod has been turned under.

A Cheap Compost for Grass.

As an example of profitable top-dressing, a Maine farmer has reported that, when his grass-lands get run down, he spreads upon them in the autumn a compost of marsh-mud and lime at the rate of ten cartloads to the acre, each load being equal to 35 bushels. This compost costs him 50 cents a load, and the application of it generally increases his crop from 1,500 lb. per acre to 3,000 lb. for about four years, the crop being timothy and clover of excellent quality; so that, at a cost of $1.25 per acre and per year for manure, he gets three-quarters of a ton of hay.

The true import of these figures may be shown by contrasting them with those of an English calculation as to the gain got by applying guano to grass. The argument was, suppose a mowing-field is yielding a ton and a half of hay to the acre, and that it is top-dressed with 200 lb. of Peruvian guano in the spring, so that the yield of hay is brought up to two tons, what will this extra

half-ton of hay have cost? Why, very nearly $6, for there has been used $\frac{1}{10}$ of a ton of the guano, and such guano cost at that time $60 the ton. Usually there would be some increase of aftermath, and in the hay-crop of the next year also, because of the application of the guano, but these gains are commonly small, and the profit from them would be offset in good part by the cost of hauling and distributing the guano in the first place. It has been well said that these prices are in the farmer's favor in case he is a buyer of hay; but if he grew hay in order to sell it, the margin for profit would be very small, especially if there be taken into the account the chances of droughty years, when guano has little or no action. But it is in years of drought that good composts often justify themselves most thoroughly.

Grass may be too Luxuriant.

It is noteworthy that the Maine farmer just now cited reports that, on trying a double dose of the marsh-mud and lime compost, he made what he esteemed to be "a perfect failure." To use his own words, "it brought in weeds, and the grass grew so rank that for two or three years it was good for nothing"; that is to say, the land had received too large an amount of active nitrogenous manure. This experiment is interesting, as indicating the limitations to which the manuring of hay-fields is really subject. It might have been supposed, not unnaturally, that the leafier the grass the better would be the hay, and it has been sometimes said, indeed, of pastures, that, "Grass being consumed in the blade, and before it is ripened, cannot grow too luxuriantly." It has been said, also, that, other things being equal, there would be less risk in manuring grass heavily than in manuring grain, because, as is well known, grain is apt to run to straw in moist seasons at the expense of the grain, both as regards quantity and quality. In point of fact, it often happens, in England, that, when unduly manured, the crops of wheat and of barley become too bulky, and get lodged so that the grain cannot ripen properly, and the expense of harvesting the crop is considerably increased, and it is important to take heed that grass is subject to a similar risk, though in somewhat smaller degree.

There are upon record many facts of experience which illustrate the impropriety of applying excessive dressings of nitrogenous fertilizers to grass-land, because such manures are apt to injure the quality of the herbage. Thus, English farmers have sometimes

noticed on grass-fields which had been liberally dressed with nitrate of soda in the spring, that while the grass soon took on a deep green color, and grew most vigorously, the sheep fed upon it were apt to suffer from scouring, and not to thrive.

Similar effects are said to be observed on grass-fields where sheep are pastured, when heavy rains in July or August follow a period of drought. Under these conditions, fields of clover or young grass which have carried a heavy stock of sheep for some months may become absolutely poisonous to lambs, and unwholesome for all kinds of stock. During the dry weather the droppings of the sheep have remained, for the most part, on or near the surface of the soil, but a warm summer rain suddenly carries down to the roots of the grass a large amount of soluble nitrogenous matters, and the rank herbage which results from this excessive manuring is known to be unwholesome. Even rabbits and hares have been known to die in numbers after eating this over-luxuriant food.

The most familiar instance of all, however, is the rank, dark-colored grass that grows in pastures about clots of dung, and in places where cattle congregate for shade or shelter. As every one knows, most animals refuse to eat this rank grass unless they are forced to do so by hunger. The experience of English graziers with guano teaches a similar lesson, though it may be urged as a general proposition that forcing manures may be used with greater freedom upon pastures than upon mowing-fields. In a rich, fattening pasture a free growth of short grass is desired, while in mowing-fields the grass should be able to stand up like grain.

It has been urged in England that as much as 6 cwt. of the best guano, or even more, might be applied at one dressing to permanent pasture-grass, particularly for sheep, if care were but taken to have the grass fed close, and not to allow it to become too long. But on mowing-fields 3 or 4 cwt. of the guano seemed to be the utmost limit to which this fertilizer could be profitably used; at least when it was applied in the spring during rainy weather as a top-dressing upon land that had been seeded down to clover and mixed grass-seeds the previous autumn. In case a second dressing of guano was thus applied, an enormous growth of ray-grass was obtained, while the clover and finer grasses that had been sown with it were nearly all smothered. The ray-grass grew very long, rank, and luxuriant, and was estimated to yield, in some instances, as much as 3 long tons of hay to the acre, but it was rotten at the bottom, much lodged, and in no sense a profitable crop.

Composts admit of even Distribution.

Composts, when applied in the spring, at least, have one advantage over stable-manure, in that they can usually be distributed more evenly upon the surface of the land. Stable-manure is apt to cohere in lumps, at the best; and when it is fresh or "long," it is wellnigh impossible to distribute it very evenly; though, as regards manure which has been spread in the autumn, it is an easy matter to smooth out the clots in the spring by going over the land with a bush-harrow. For killing moss also, which is one of the purposes of top-dressing, loamy composts have probably a decided advantage over stable-manure of equal richness in fertilizing ingredients, because of their superior covering power.

There are doubtless cases, especially upon clayey land and on low meadows, where mere coal-ashes applied as a top-dressing to grass would serve an excellent purpose. Chip-dirt, pond-mud, and dust washed from roads, and even beach-sand, have all been applied to grass-land with advantage. As the farmers say, they keep the surface from "binding." This remark would appear to apply more particularly to poor, worn-out fields. In the experiments of Lawes, no advantage was gained from sawdust or from chopped straw when applied to good old permanent grass-land at the rate of 2,000 lb. to the acre, either by themselves or admixed with artificial fertilizers. It has occasionally been suggested, indeed, with considerable force, that the fact that the sods of old grass-land rest upon a fine, dark, friable mould, teaches the importance of imitating nature, and of using composts of vegetable mould for top-dressing newly laid grass-fields.

The free use of composts in conjunction with small quantities of appropriate chemical fertilizers for top-dressing grass fields, would probably be a considerable improvement upon the system of husbandry which prevails nowadays in New England.

It is to be remembered always that there are hay-lands in England, especially near London, which have been kept in profitable grass for long terms of years by simply top-dressing them with horse-manure. Loudon tells of such fields on tenacious clays that have been rendered exceedingly productive by the abundant application of stable-manure hauled out from London.

Different Fertilizers favor Different Grasses.

One of the most noteworthy facts with regard to the manuring of grass-lands is, that very different kinds of herbage are "brought

in" by different kinds of manures; that is to say, one kind of grass in the mixture that occupies a field will prosper especially when the field is manured in a given way, and will tend to crowd out the other grasses. But if the field is manured in some other way, another grass, or other grasses, are liable to get the upper hand. In general terms, it may be said that when active nitrogenous fertilizers are applied to grass-land, certain individual species will be forced into luxuriant growth, though it may happen that one or another kind of grass may be particularly favored, according to the soil, the character of the herbage, and the kind and amount of the fertilizers employed.

It has long been noticed here in New England that wood-ashes when applied to grass-land tend to bring in white clover, and that plaster of Paris is often an excellent manure for clover. But, as is now known, the plaster acts by setting free potash from the soil. Indeed, the celebrity of plaster as a manure depends largely upon the extensive use which was made of it at one time, a century ago, upon the clover-fields of Europe. In one word, mowing-fields dressed with potassic fertilizers give an abundant growth of clover rather than grass. Lime also has often been noticed to promote the growth of white clover. It has been said of some districts in England, that with the more sparing use, in recent years, of lime in pastures, white clover has become much less abundant than it was formerly. It is said, too, that white clover often grows vigorously on limestone soils. Some European writers have said that even ray-grass does not prosper unless the land has been limed.

The Experiments of Lawes and Gilbert.

This question of the influence of different classes of manures upon the growth of grass was thoroughly studied by Lawes and Gilbert some years ago, and highly interesting results were obtained by them. They found, like our own farmers, that potash increased the proportion of leguminous plants on a grass-field; but that when soda was substituted for the potash there was a notable diminution in the proportion of leguminous herbage. They found, moreover, that by far the most complex mixtures of herbage were obtained upon unmanured fields, or in general upon fields that yielded light crops; that is to say, a comparatively large number of species of plants were found in the hay from such fields, and there was no such predominance of a few species as occurred in the

more bulky crops obtained from manured fields. This remark was true not only of the grasses proper, but of weeds and other volunteer plants. As a rule, greater simplicity of herbage was coincident with any considerable increase of crop, no matter what kind of manure had been used; and there was, at the same time, a greater predominance of the grasses proper, and of some few special kinds of grasses or of clover.

For these experiments, 6 perfectly level acres of an old park which was known to have been kept permanently in grass for more than a century were measured off into half-acre plots. Before the experiments, the average yield of hay had been from 1.25 to 1.75 long tons to the acre, and the aftermath had always been fed off by sheep. "The land is a somewhat heavy loam, with a red clay subsoil resting upon chalk; and although not artificially, it is thus naturally very well drained."

Influence of Farmyard-Manure.

It was observed that farmyard-manure, beside increasing the total product, increased the amount and the proportion of the grasses proper. It diminished the variety of herbage and the proportion of leguminous plants and weeds; though it was still true that the herbage was much more complex than that got by using active artificial fertilizers. During the 8 years that farmyard-manure was applied, there was obtained an average annual crop, from one cutting, of 4,800 lb. of hay to the acre, which was 2,139 lb. more per acre than was got from the unmanured land.

Farmyard-manure, plus 200 lb. of ammonium salts, gave a considerably larger crop than the farmyard-manure alone, and the herbage took on a darker green color. The true grasses became more prominent, while leguminous plants and weeds (excepting sorrel) were less conspicuous than on the unmanured plot or on that which had been dressed with farmyard-manure alone. The crop was very luxuriant, strong, and thick-bottomed, and had a fair proportion of both leaves and stems. It comprised a considerable variety of grasses.

Influence of Minerals.

Mineral manures alone, whether a mixture of salts of potash, soda, or magnesia, or superphosphate of lime, increased the crop moderately, and caused it to exhibit a marked tendency to form seeds, and to ripen rather than to produce luxuriant foliage; they rather diminished the proportion of true grasses, and considerably

diminished the proportion of weeds. But such mineral manures greatly increased the proportion of leguminous herbage, especially that of red clover and of the meadow-vetchling. Potash was evidently the most important constituent of these mixtures of fertilizers, both as regards the growth of the true grasses and of leguminous plants. On ceasing to apply potash-salts much less hay was produced, even when an abundance of all the other ash-ingredients was put upon the land.

Influence of Ammonia.

Ammonium salts alone considerably increased the yield per acre, and they increased the proportion of grasses, while they diminished the leguminous plants and weeds. In point of fact, clover and the like were wellnigh excluded when the field was manured with ammonium salts. It was noticed that the grasses tended very remarkably to run to leaf, and that the plants had comparatively little inclination to form stems or seed; just as was the case with the field of the Maine farmer above mentioned, who overdid the dressing of the marsh-mud and lime compost. There was a dense bottom herbage, the plants showed little disposition to flower, and the crop was very late in coming to maturity. Many years previous to these experiments of Lawes and Gilbert, Schattenmann had observed that ammonium salts applied to grass-land greatly promote the growth of the true grasses, as they do of grain-plants, while they have no beneficial effect on the growth of lucern and the clovers. The results of still other experiments, made long ago by Kuhlman, are given in the table: —

From one acre of land	There was harvested lb. of hay		
	1st year.	2d year.	3d year
Unmanured, ...	3,361	3,948	2,930
Dressed once with 209 lb. of sulphate of ammonia, . . .	4,896	3,670	
Again dressed with sulphate of ammonia, in the third year,			4,570

As was to be expected, the action of the fertilizer was felt only in the year of its application. But on new grass-land very great advantage may sometimes be gained by applying fertilizers which shall enable the crop proper to grow rapidly enough to smother, once for all, many of the weeds which are disputing with the young grass-plants for the possession of the land. In the experiments of Lawes and Gilbert, mixtures of nitrogenous and potassic or other mineral manures gave by far the largest increase of crop, and the proportion of grasses proper was much larger than was obtained in any of the other experiments. Clover and other legu-

minous plants were practically excluded, and the number of species of weeds and the total amount of weedy herbage were but small, though some few individual weeds grew luxuriantly. The great bulk of this large crop was made up of comparatively few species of grasses, and the development of stems and seeds was remarkable. Although very luxuriant, the grass on the plots fertilized with ammonium salts, together with potash and other minerals, ripened fairly well unless a very large quantity of ammonia had been applied, in which event the herbage came to consist almost exclusively of true grasses, the most prominent among which were of large habit and free growth, while leguminous plants, and weeds also (excepting sorrel), were practically excluded.

In the experiments where 400 lb. of ammonium salts were used in conjunction with potash and other ash-ingredients, considerably more than twice as much hay was harvested during 20 consecutive years as was got without manure, nearly twice as much as was got by using the ammonium salts alone, and nearly 1.5 times as much as was got by using nothing but mineral fertilizers. On doubling the quantity of the ammonium salts, while the mixture of minerals remained as before, a still further increase of hay was obtained, so that an average yield of about 3 long tons of hay from one cutting was obtained annually during a period of 20 years. Meanwhile, the herbage came to consist almost exclusively of a few free-growing grasses. "These grasses take possession of the ground very much in tufts or patches, and grow coarse, strong seed-stems, and broad, flaggy, dark-green leaves. The herbage is, in fact, very coarse, often laid, and dead at the bottom before it is ripe; indeed, it generally matures irregularly and imperfectly, yielding hay of low quality. Though if the grass were fed off young, or cut green for feeding, it would probably be fairly good food."

Influence of Nitrate of Soda.

Nitrate of soda alone considerably increased the product of true grasses, and tended very strongly to produce "root-foliage;" i. e. the crop was much more leafy than stemmy, it matured late and, instead of the stems and the leaves upon them growing longer, much foliage was developed from the bases of the stems. But it was true, nevertheless, that the plot heavily dressed with nitrate of soda exhibited a very different general aspect from that of the ammonia plot. The herbage of the ammonia plot was almost ex-

clusively leafy and extremely dark green, yet there was highly restricted vegetation (carbon assimilation) and scarcely any tendency to maturation.

The nitrate plot showed somewhat similar characters, but in a very much less degree; the herbage was much more characteristically leafy than where mineral manures were employed in conjunction with the nitrate, but there was much more luxuriance, much more tendency to form stem, and a much lighter and healthier color than with the ammonia. Under the influence of the nitrate, the herbage was more complex than it was with ammonium salts, and the grasses were less patchy and tufty, not of so dark a green color, and they yielded more stem, much of which bleached rather than ripened. The continued application of nitrate of soda, at the rate of 275 lb. to the acre, gave considerably larger crops of hay than were obtained on applying as much sulphate of ammonia as contained twice as much nitrogen as the 275 lb. of the nitrate did. But, naturally enough, no great increase of gain was obtained on doubling the dose of the nitrate.

As was the case with ammonium salts, leguminous plants were at a disadvantage in grass-fields manured with nitrate of soda. In fact, leguminous herbage was almost entirely excluded from the grass-plots whenever the nitrate or ammonium salts were applied, either alone or in combination with mineral manures; but the nitrate was rather less efficient in this respect than the ammonium salts. Nitrate of soda is in any event a better manure for leguminous plants than sulphate of ammonia is; and the nitrate is hardly so well fitted as ammonia for enabling the true grasses to smother some kinds of weeds.

Nitrate of soda, used in connection with potash and a mixture of mineral manures, gave larger crops of hay than were got either from the nitrate or from the minerals by themselves, and the crops ripened better than when nothing but the nitrate was used. The true grasses predominated, but there was a somewhat larger proportion of leguminous plants than grew upon the plots which got nothing but nitrate of soda. The larger the dressing of the nitrate used with the minerals, the smaller was the proportion of weeds.

It appeared that 275 lb. of nitrate of soda to the acre yielded nearly as heavy crops as were obtained on using 550 lb. of the nitrate; and that a given quantity of nitrate-nitrogen produced a

considerably larger crop of hay than the same quantity of ammonia-nitrogen produced, both when the nitrogenous fertilizers were applied by themselves, and when they were used in conjunction with minerals. On the plots where 550 lb. of nitrate of soda to the acre were used, with the minerals, an average of some 6,380 lb. of hay per year and per acre were obtained during 18 years, and on those plots to which 275 lb. of the nitrate were applied, the average annual yield of hay was 5,200 lb. to the acre.

Influence of Superphosphate.

Superphosphate of lime, by itself, gave an annual increase of about 2 cwt. of hay to the acre during several years, but this increment soon diminished to such an extent that the plot fertilized with nothing but superphosphate yielded hardly any more produce in the course of 17 years than was got from unmanured land, and it gave less than two-thirds as much produce as was obtained on using a mixture of mineral fertilizers. It appeared, indeed, that the superphosphate by itself was a much less useful manure for grass than potash salts taken by themselves, while for clover and other leguminous plants the superior merit of potash is acknowledged.

Mixtures of superphosphate of lime and ammonium salts gave an average annual increase of 17 cwt. of hay per acre during 7 years, and in the course of 17 years such mixtures gave more than one-third more produce than was got by using ammonium salts alone. Leguminous herbage and weeds also, excepting sorrel, tended to disappear, while hardy grasses, such as sheep's fescue and red-top remained.

In default of farmyard-manure, some English farmers have obtained remunerative results by top-dressing their mowing-lands with a mixture of 1 to 1.5 cwt. of nitrate of soda, 2 to 2.5 cwt. of plain superphosphate, and 3 cwt. of kainit to the acre. It is said that this mixture tends to bring in clover, and is specially favorable for clover, evidently because of the presence of the potash salt; but it is important not to use too much of the nitrate in such cases, lest the clover should suffer. Thus, in an experiment reported by Voelcker, where a plot of poor, light, sandy land, which had been seeded with clover and Italian ray-grass, was dressed with 4 cwt. of superphosphate and 4 cwt. of nitrate of soda to the acre, the clover-plants were practically smothered by the ray-grass, which grew very long and coarse. The quality of the hay ap-

peared to be scarcely better than good oat-straw, and very few clover-plants could be seen. In somewhat the same sense, perhaps, an instance has been recorded where clover sprang up in abundance on land dressed with this mixture, where soot was subsequently applied at the rate of 40 bushels to the acre, with the result that the clover disappeared from the land as if by magic, and a heavy but coarse crop of grass took its place.

Sewage irrigation, when applied to mowing-fields, has been found, like other active manures, to develop grasses chiefly, particularly a few kinds of free-growing grasses, such as the rough-stalked meadow-grass (Poa trivialis), couch-grass (Triticum repens), orchard-grass (Dactylis glomerata), woolly soft grass (Holcus lanatus), and perennial ray-grass (Lolium perenne). The herbage of such meadows is very simple, and is wellnigh free from leguminous plants and weeds, excepting a few buttercups, docks and dandelions. Since the grass of such meadows is cut when young and green, it is little matter that some of the grasses just mentioned would make rather coarse and inferior hay if left to approach maturity.

Summary of Lawes and Gilbert's Results.

A few of the numerical results obtained by Lawes and Gilbert in the earlier years of the experiment may here be given. The figures relate to the hay-crop proper, no account being taken of the second growth of grass which was pastured by sheep and was estimated to amount in these years to from 1,400 lb. per acre on the unmanured land to 2,200 lb. on the land that was dressed with the mixture of mineral fertilizers and 400 lb. each of the ammonium salts.

On the average of the first 7 years of the trials, there was obtained, per year and per acre, from land that had received

	Hay, lb.	Nitrogen, lb.	Ashes, lb.
No manure	2,800	40	168
200 lb. each sulphate and muriate of ammonia	3,700	62	205
Mixture of mineral fertilizers [1]	3,900	57	261
Ditto, and 200 lb. each of the ammonia salts	6,400	78	404
Ditto, and 400 ditto, ditto	6,900	98	436
Superphosphate of lime [2] (4 years)	3,200	44	209
Ditto and 200 lb. each of the ammonia salts (4 years)	4,900	70	286
14 tons farmyard-manure	4,800	59	329
Ditto, and 100 lb. each of the ammonia salts	5,500	68	372

[1] Composed of 300 lb. sulphate of potash, 200 lb. sulphate of soda, 100 lb. sulphate of magnesia, and superphosphate of lime as in the next note.

[2] 200 lb. bone-ash and 150 lb. sulphuric acid of 1.7 sp. gr.

275 lb. nitrate of soda (5 years)	3,700	55	235
Ditto and the mixture of mineral fertilizers[1] (5 years)	4,900	65	329
550 lb. nitrate of soda (5 years)	4,000	64	243
Ditto, and the mixture of mineral fertilizers (5 years)	5,900	70	364

It has been said, by Warington, of these experiments of Lawes and Gilbert, "It is difficult now to believe that the herbage was ever alike over the various plots, and that the striking differences in the development of individual species of grasses, clovers and weeds are simply due to the persistent application of certain chemical salts."

Effect of Fertilizers on Clover.

In a special set of experiments on the growth of red clover with the different manures, Lawes and Gilbert sowed barley and clover on land where a heavy crop of Swedish turnips had just been grown by the aid of farmyard-manure and superphosphate. In the second year of this clover, various fertilizers were applied to different plots of it, and very heavy crops were obtained. Thus from the unmanured plot some 14 long tons of green clover were got in three cuttings, or, say 3.75 tons of hay; and 17 or 18 tons of green produce (equal to from 4.5 to 5 tons of hay) were obtained from plots that had been fertilized with superphosphate — by itself, or admixed with sulphate of potash — or with mixtures of the sulphates of potash, soda and magnesia. No benefit was derived from the addition of ammonium salts or of rape-cake to the mixed mineral fertilizers.

The clover-sod above mentioned was ploughed under, wheat was sown (which gave an excellent crop), and clover was sown upon the wheat. But this clover failed, and on ploughing the wheat-stubble and again sowing clover, as well as fertilizers in considerable variety, only a mediocre crop was obtained. Like the previous clover-crop, this one did better on the plots dressed with potassic fertilizers and superphosphate than on those treated with other kinds of manures. This crop improved for a time, but became diseased in patches during the second year of its growth, though it appeared that the progress of the disease was less conspicuous where potassic and phosphatic fertilizers had been used, and especially where they had been used by themselves without any admixture of ammonium salts or of rape-cake.

Generally speaking, a more or less clearly marked increase of

[1] See note 1, on preceding page.

crop was noticeable where potash salts, or potash salts admixed with superphosphate, had been used. Yet it was evident that "The alkalies, potash, etc., have ceased to be as useful as manures for the clover as they were at the commencement of the experimental period. . . . This decline appears to be connected with some defective condition within the soil."

Subsequent efforts to grow clover yet again on this land gave no satisfactory crops. "The produce in sixth season of the attempt to grow clover continuously on the same land, and, after two years of entire failure, was in every case small." But a very luxuriant and productive crop of barley was grown on this "clover-sick" land immediately after the last meagre crop of clover.

Lawes and Gilbert express themselves as satisfied "that no direct supply of manure, in the ordinary form of farmyard-dung, or of the current artificial fertilizers, is capable of restoring the soil from which a heavy crop of clover has been taken, to a condition of immediate productiveness for the same crop." Yet in a rich old garden, not far distant from the experimental field, they grew a small patch of red clover continuously, with great success, during the very same years which were devoted to their field experiments. From 1854 to 1859 they mowed this garden clover 14 times without any resowing of seed, and they estimated that the average yield of hay, per year and per acre, was at the rate of 4 long tons and 7 cwt. from the unmanured plot during the 6 years, and at the rate of 3 tons, 19 cwt. during the last 4 years. It was observed that the yield was considerably increased by adding gypsum, or, better, by adding a mixture of the sulphates of potash, soda, and magnesia, and superphosphate to this permanent garden clover.

Guano on Lawns.

It has sometimes been urged that guano is specially beneficial to lawns, because it not only promotes the growth of true grasses, but may be made actually to destroy some weeds. Thus it is said that if guano is scattered in the early morning, in fair, dry weather, at the rate of 3.5 lb. to the square rod, on a lawn infested with white-weed and plantains, these weeds can be eradicated; for their broad and bedewed leaves receive and hold the guano, and are poisoned by it. After the growth of the weeds has thus been checked, and showers occur, the guano will be washed into the soil, and stimulate the growth of the grass. A lawn guanoed in this way will appear brown and dirty for some little time, or until the grass has

grown high enough to conceal the seared leaves. If, instead of proceeding in this way, the guano were strewn in dull, showery weather, it would excite a vigorous growth of grass without turning the field brown, and without destroying the white-weed, excepting in so far as the grass might override it.

Weedy Grass is apt to make Bad Hay.

One advantage to be noted in favor of using such fertilizers as would tend to crowd out weeds is, that the true grasses dry more readily than leafier plants can. Consequently, pure grass-hay is distinctly less liable to become mouldy than weedy hay. This consideration is specially important in case the hay is to be fed to horses, or to be sold for this purpose. Another point to be borne in mind is, that the judicious manuring of some hay-fields might bring the grass into such condition that it could be mown at a different time from the unmanured fields of equal age, whereby some saving of hurry and anxiety at the time of the hay-harvest might be made.

The crowding out of some kinds of plants by others has been dwelt upon by Darwin, who naturally looked at the matter not so much from the chemical point of view as from that of the natural historian. He found that seedlings suffer most when they germinate in ground already thickly stocked with other plants, and that, when turf which has long been mown or browsed is allowed to grow, the more vigorous plants gradually kill the less vigorous, though fully grown plants. Out of 20 species on a little plot of mown turf, three feet by four, 9 species perished when the other species were allowed to grow up freely.

Influence of Clover in Grass-fields.

In discussing the manuring of mowing-fields it is important to consider the influence of the clover-plants which are so often grown in conjunction with timothy. As has been stated in Volume I, clover obtains food in a different way from grass, and does, in fact, derive benefit from the free nitrogen of the air. Doubtless the grass-plants may put to profit some part of the nitrogen which the symbiotic fungi on the clover-roots accumulate from the air. This result might occur at any time whenever any of the nodules should happen to die; and it may be that grass growing among clover may get some good from the secretions of the micro-organisms which the clover supports. In any event when the clover-plants come to die out gradually, after a year or two, they will

naturally leave their roots in the ground, and the grass-plants will have access to the stores of nitrogen which these roots contain. Hence the sowing of clover-seed with grass may serve to distribute in some measure the original manuring through a term of years, or to revivify the manure as it were. It is thought, moreover, that the porosity imparted to the land by the numerous roots of the clover, which leave openings and channels when they decay, is a matter of considerable practical importance, particularly upon heavy land.

Lawes and Gilbert, in their experiments on the continuous fertilization of grass-fields, found that the plot dressed with a mixture of mineral fertilizers devoid of nitrogen yielded in the course of 20 years more than 1.5 as much gramineous herbage as was grown without any manure, and that while without manure there was a decline in the second 10 years compared with the first, there was with the mineral manure a considerable increase during the later period. Meanwhile, there was not nearly so much increase of weight of the leguminous herbage by the mineral manure as there was of the gramineous, but the proportional increase was much greater, there being more than 4 times as much grown with the mineral manure as without manure, and there was more also in the second period than in the first.

Strangely enough, in view of the chemical composition of clover-hay, and the great estimation in which clover is held in some of the best farming countries of the world, there are not a few farmers in New England who maintain that it is on account of the considerations just now mentioned, rather than because of any direct gain obtained from the clover itself, that they persist in sowing clover-seed together with their grass. Possibly this opinion may be justified by the high cost of labor in this country, and it may well be true, that clover needs to be fed out green (as is usual abroad) in order to produce its best effect.

When it is to be used as hay, clover should be mown rather early and be cured with special care. Even when at its best, horse-keepers do not care to buy clover-hay because of the liability of the leaves to be "dusty" from the presence of moulds or other fungi.

Undoubtedly, one reason why the seeds of clover and of grasses are so often sown together is that, under ordinary conditions as to fertility, a given piece of land occupied by several different kinds

of plants will yield a larger crop than if the land bore only a single species. Even as regards the true grasses it is generally admitted that a larger weight of forage may be got from a field on which several species of grasses are growing than when no more than two or three species are present, and even better results are to be expected when clover is admixed with the grasses, since, as Darwin puts it, "The same spot will support more life if occupied by very diverse forms." "We see this," he says, "in the many generic forms in a square yard of turf (I have counted 20 species belonging to 18 genera), or in the plants and insects, on any little uniform islet, belonging to almost as many genera and families as to species. We can understand this with the higher animals, whose habits we best understand."

A good illustration of this argument is afforded by Marshall's dictum that "A thin crop of wheat may be improved by sowing oats over it in the spring." "In case," he says, "a wheat-field has gone off in patches in the spring so as not to be worth standing alone, as a crop, oats may be harrowed in on the lean and vacant places, and a full crop of oats and wheat be obtained, while weeds will be smothered. The grains may be separated well enough in winnowing by a machine-fan properly regulated so that the head wheat will be acceptable to millers, at least in those districts where wheat is habitually grown after oats and is seldom or never wholly free from the admixture of some grains of oats.

Mulching of Grass-land.

The fact that mere loam has occasionally been used with success for top-dressing grass naturally suggests the inquiry in how far mulching can be made to supplement or supply the need of manure on grass-land. Though manifestly open to doubt, the opinion is not uncommon that very nearly one-half the beneficial effect of stable-manure, when used for top-dressing grass, may be due to its acting as a mulch. Indeed, Gurney long ago recommended that rich pastures should be mulched methodically. In his practice, straw of wheat, oats or rushes was lain lightly and evenly upon growing grass, at the rate of from one ton to a ton and a half to the acre. At the end of a fortnight the mulch was raked off into bunches, cattle were turned in to eat the grass, and at the end of a fortnight (more or less, according to the richness of the soil, the number of cattle, the season, and the weather) the mulch was relaid. These processes were repeated at about the stated

intervals throughout the season. Good straw was found to last all summer, and to be worth saving for winter litter. During the growing season it was found to be necessary to rake off the mulch frequently, lest the grass should grow through it and become entangled with it. The growth of white clover was noticeably favored in these experiments.

Mr. Olcott in Connecticut reports the successful renovation of worn-out mowing-fields by sprinkling upon them lightly, in August, timothy and clover-seeds and covering the land with bog-meadow hay which was in some instances spread at the rate even of 2.5 tons to the acre. He says, "Whoever saw a lock of hay dropped in crossing a meadow without producing an increase of grass. . . . A mulch of hay breaks and softens a bound-up sward almost equal to a winter's frost, a ploughing, or a coat of stable-manure."

An interesting method of mulching fields of young clover in Northern Ohio for the sake of helping forward the young clover, of securing an even stand of the crop and in order to fertilize the field, has been described as follows: When the best of the clover-plants are nearly a foot high, the crop is mown, with the machine, just before or just after rain. The knives of the machine are set as high as possible, and pains are taken to cut off only the tops of the best plants and of the wheat-stubble in such manner that they shall fall evenly upon the land. There they shrink upon drying, and lie closely between the young plants to serve as a mulch. Unless the season should be exceptionally dry, this process of clipping is repeated, not later than the middle of September, when the plants have again reached a height of nearly one foot. (Terry.)

One reason, doubtless, why young grass is more liable to be winter-killed than that which is old, is due to the fact that the old grass is protected by the dead herbage (the so-called fog) that covers the soil. Hence, in exposed situations, and in localities where snow does not lie long upon the ground, it is thought to be well to sow rye (or wheat) with the grass-seed in autumn, because the leaves of the grain-plants, when killed by frost, will still cover the young grass-plants, and so help to prevent them from being frozen out. It has been questioned whether it would not be well, in this sense, when land is seeded down to grass in August, to sow with the grass-seed some oats very thinly, or some barley

or other quick-growing plant which would be killed by the frost. The idea is that the oats, or what not, would shoot up to a height of several inches before the advent of a killing frost, and would finally fall down and cover the surface of the ground, and protect it both by acting directly as a mat and by holding snow upon the land. But in trying any such experiment as this, it is important to sow the field rather early in the season, and that there shall be moisture enough in the land to enable the oats (or other plant) to get well started before the cold weather of autumn sets in. It is hard to say just what plant would best serve this purpose. Perhaps barley would be better than oats, or perhaps vetches or peas would answer. Possibly some flowering plant, like balsams, for instance, whose seeds could readily be procured in large quantities, would do. It is a subject which intelligent farmers might well study. There would seem to be needed a rather coarse plant, that will grow rapidly in cool autumn weather until nipped by frost. According to H. Stewart, a pound of turnip-seed to the acre, sown with grass-seed in the autumn, will afford excellent protection for the young grass. The broad leaves of the turnip give welcome shade and protection from early frosts, and the roots dying in the winter furnish useful food for the young grass in the spring.

Pasturing of Mowing-fields.

Another matter intimately connected with the mulching of mowing-fields is the question whether or not it is advisable to pasture cattle upon such fields in the autumn. The practice is actually a very common one in New England, although there are many farmers who condemn it utterly. It is not easy to understand the reasons of such sweeping condemnation, though it is generally admitted that timothy is ill-adapted to withstand the biting of animals, and good fields of it may well be protected from them. Clover, in particular, must be permitted to bear leaves in late summer or autumn, in order that food shall be stored up in its tap-roots for the support of the early shoots of the next spring. It is a fact of observation that fields of red clover may be completely ruined when cattle are allowed to feed them bare after the hay-harvest.

Voelcker found that more nitrogen was left in the land at the end of the second year by the roots of a clover-crop, in case the plants were allowed to stand for seed in the first year, and pastured in

the second year, than when the clover was immediately fed off. The explanation is that the roots, and the symbiotic bacterium upon the roots, develop much more perfectly when the plants are allowed to grow without frequent checks than when they are subjected constantly to the nibbling of sheep. But pasturing cattle will tend to destroy several kinds of weeds — notably the wild carrot — which are apt to flourish in grass-lands in late summer, and their trampling may sometimes do good on light land, especially as a means of destroying moss. This destruction of weeds is really a point of no small importance, and sheep, if judiciously managed, might do more good in this respect than cows. If it were customary (i. e. if it were economically practicable) in the vicinity of Boston to pasture sheep on the mowing-fields in late summer and early autumn, it would hardly be possible for the wild carrot, the ox-eye daisy, chicory, etc., to grow so uncontrolled as they do now in this locality.

The fact of the matter would seem to be, that on old mowing-fields the practice of pasturing with moderation in early autumn may be commendable, especially where the sod is thick and the grass vigorous, while it may be hurtful to timothy and clover, and especially to poor, dry, exposed fields. Care should always be taken neither to feed too closely nor too late. Enough blades of grass should be allowed to grow that the roots may be fully supported. For this reason, it would be unwise to turn cattle into a hay-field immediately after the grass had been mown. Ordinarily, the temptation to do so is not great, for it is an old observation that cattle seldom thrive on such pasturage. Some persons have argued that the stubs of the old grass-stems prick the noses of the animals, and hinder them from feeding freely; but, as Marshall has urged, the reason why the cattle fall away probably depends upon the innutritious quality of the grass. The grass which the scythe leaves must consist chiefly of root-leaves and stubs, which have given up much of their goodness for the support of the upper parts of the plant, and of underling plants which have never had opportunity to grow properly, and which may, fairly enough, be compared with grass which has grown under a hedge, or in the shade of a wood. Anything that works to leave the ground absolutely bare is injurious, since the cold of winter tends to kill the roots. So, too, the roots would be liable to die,— that is to say, they might be killed by heat,— if the fields were depastured im-

mediately after mowing, and there can be little doubt that the presence of cattle in the fields at that season is to be deprecated.

"Fogging."

In the extremely humid climate of Southern Wales, where hay can hardly be made at all, and can rarely be well made, a practice known as "fogging" was at one time prevalent. Cattle were taken out from some of the pastures in May or June, and the year's crop of grass was left untouched until the following spring, when cattle were turned in to feed upon it. It was asserted by the advocates of this practice that an acre of such fog would keep more stock, and keep them in better condition, than an acre of hay, while all the risks and expenses of haymaking were avoided. It was held that the grass-land was improved by the seeds shed by the old grass, and that the mat of fog sheltered the young grass and enabled the tender shoots to come up sooner than they could have done if exposed to the bleak winds and frosty air of the cold springs of the locality. The old herbage was said to combine so well with the succulent young grass that cows fed upon it produced a large increase of milk.

However this may be as regards pastures, and no matter how useful the old fog may be as a protection to the field in winter, it is evident enough that, as the spring advances, too thick a coating of dead grass upon a mowing-field may be a serious annoyance. It encumbers the land, hinders the growth of the young grass, tends to smother the roots, and is a real detriment to the field. All this, beside the liability of its interfering with the scythes and rakes at the time of haymaking. Another serious objection to a thick coating of dead grass is that it is apt to harbor great numbers of field-mice, which feed upon and destroy the grass-roots. It will be noticed that careful gardeners take pains to rake off the dead grass from lawns, and grass-plats, and borders about houses, every spring, in spite of the fact that there is usually no very large amount of it. There can be little doubt that the removal of dead grass from a thick lawn is a benefit to the living grass, whatever may be the possible utility of the fog on a thin old mowing-field.

The burning of dead grass by savages, all over the world, for the purpose of starting a new growth, is a fact of the same order. Mr. Olmsted, speaking of February as "a spring month in Texas," says: "The dreary burnt prairies, from repulsive black, changed at once to a vivid green, like that of young wheat. The unburnt

districts, covered with the thick mat of last year's growth, were a month behind." Hence, on this account also, the argument against mowing or pasturing hay-fields in autumn must be taken with many grains of allowance.

CHAPTER XXXIX.

THEORY AND PRACTICE OF MAKING HAY.

THE art of hay-making admits of several variations, though the principles upon which it depends are few in number and simple in appearance. Occasionally a farmer may be heard to assert that hay should be made in such wise that the product shall be "dried grass"; and the idea seems reasonable enough at first sight. There is a note of practicality in the remark, moreover, that catches the ear, and it seems to consist with the well-known fact that young grass is particularly nutritious. But the statement might easily mislead an inexperienced person, and can only be accepted as true when accompanied by explanation and qualification. It is to be presumed, indeed, that those farmers who make this remark do not mean to imply that the hay shall really resemble pasture-grass, for the conceptions "hay" and "grass" are very properly separate and dissimilar in the minds of practical men. For example, if, to a farmer boasting that his hay is made so well that it is really nothing but dried grass, the question should be put, "What! do you feed your horses on rowen?" he would probably find himself somewhat puzzled for an answer. For it is notorious that, when horses are fed upon soft, succulent food, such as grass, or vegetables, or rowen-hay, their muscles become "soft." In reality, the flesh produced by such food is, comparatively speaking, watery. Animals perspire easily when thus fed, and they are not fit for hard work. Hence the popular conviction that horses, in particular, need "ripe" or mature hay. This feeling was well expressed by a farm-hand, who, on being directed to feed out a lot of rowen-hay to some idle horses, remarked that it would be just as well to give them curled hair.

The truth of the matter is, that, in order to get good hay, the grass should be mown at the time when it is in the condition best fitted for the purpose to which it is to be put; and the crop should then be secured with as little waste as possible. Moreover, in case

the hay is to be sold, it should be made in such manner that it may present a fine appearance.

Sources of Waste in Hay-making.

There are several well defined sources of waste in hay-making. First, the risk of washing by rain after the grass has been cut, whereby sugar, dextrin, and other soluble matters, including an appreciable quantity of ash-ingredients, are dissolved and removed. Secondly, the development of fungi in damp hay, both in hay that has been wet by rain and in that from which the natural juices have not been properly dried off. This question of fungi in damaged hay and other fodders is doubtless a very important one, since some of the fungi, or at the least the altered materials upon which they are found, are distinctly hurtful to animals. Several instances have been recorded where mouldy grain, notably oats and Indian corn, fed out to horses have caused death, and it is a popular belief that farm animals are not infrequently injured by eating hay that has been partially rotted by exposure to dampness. Horse-keepers are particularly careful not to feed out hay which is mouldy or "dusty." Several farmers have urged that one great advantage in using hay-caps is to be found in the fact that they hinder the development of fungi.

Unfortunately, very little seems to be known as yet concerning these harmful fungi. It would be well to know certainly whether hay or oats damaged by them could, in all cases, be made harmless by steaming; though it is open to grave doubts, an impression prevails that mouldy fodder could in this way be rendered completely innocuous. The advocates of cooked fodder have been accustomed to urge that the steaming of damaged hay, to which a little bran or meal has been added, will make it palatable to cattle, and that the animals prosper on such a diet. There can be no doubt that, as a general rule, it is safer to feed damaged hay after cooking than before. But it must always be remembered that the danger in eating animal matter which has once begun to putrefy — as in the case of poisonous sausages, tainted milk, "picnic ice-cream," "canned corn-beef," or the like — may not be due to the actual presence of micro-organisms, but to products of decomposition which result from the action of these organisms on the animal matter, and which may have been formed previous to the time when the food was eaten. Some of these products of decomposition, known as toxines, or ptomaines, are virulent poisons. Some of

these bodies are definite chemical compounds — related to the alkaloids, such as strychnine — which may not be mitigated or removed, or in any way affected by strong heat or intense cold, such as would quickly destroy the micro-organism which produced them.

Salting of Hay.

The real justification of the common practice of salting hay when it is pitched into the mow or stack, or of scattering slaked lime upon it at that time, is undoubtedly to be found in the power of the salt and the lime to check the growth of fungi. The salt and the lime both work to check fermentation, and to prevent moulding, and the use of them is undoubtedly commendable in special cases, as when partially cured hay has to be stored in bad weather, or as in the short days of autumn, when rowen cannot be properly dried in the fields. Six or eight quarts of salt to the ton of hay are thought to be sufficient even when the hay is hardly half dried when housed. It is an interesting fact that, in the interior of the country, — that is to say, far from the sea-coast, — where animals rarely get all the salt they would like, cattle often prefer hay that has been salted, under the conditions just now described, to the best hay that has been made perfectly, according to the usual methods. Many people have argued from this circumstance, that all hay should be slightly salted, and the practice of doing so has become general in many localities. It is no uncommon thing to see New England farmers scattering half a peck of salt to the ton of hay, as the latter is thrown upon the mow, no matter how good the hay may be. In so far as the appetites of the animals may be increased, the putting of salt or lime upon well cured hay may be well enough, and for saving damp or weedy hay both these additions have undoubted merit; but there is really no need of them on hay that has been well dried and properly housed. The salting of the coarser kinds of forage, such as bog-meadow hay and straw, either at the time when they are placed in the mow, or after they have been passed through a hay-cutter, is an approved device for making such food palatable to cattle.

In case the conditions as to labor are such that dry straw, as well as salt, can be mixed with the damp hay, layer by layer, when the latter is to be stacked out of doors, as is usually done in Europe, it is said that still better results are obtained than can be got by the use of salt alone. The straw imbibes the moisture from the damp hay, and much of its flavor also, so that cattle will readily eat the entire contents of such a stack, the straw as well as the hay.

Hay that is admixed with some kinds of weeds stands in special need of being salted. For example, in case a field infested with white-weed or buttercups were mown early in the season, to prevent these weeds from seeding, it might not be found easy in "catching weather" to dry the young grass and the succulent herbs completely, and it would be well to salt such hay freely as it is stored in the mow. It may be said, in passing, that hay charged with these particular weeds is highly nutritious, and excellent for milch cows.

The preservative action of salt in hay-mows is well illustrated by the fact that, on the sea-coast of New England, it is easy to keep watermelons that have ripened in September fresh and sound until December, by simply packing them away in a cool barn in "salt hay," i. e. hay made from grass grown upon salt marshes. Of late years, large quantities of this salt-marsh hay have been used for packing bananas also, which are transported by rail into the interior of the country.

Crumbling of Leaves and Dropping of Seeds.

Beside the risk of loss from washing, and from the development of fungi, there is the waste of delicate leaves on handling hay which has been allowed to become very dry and crisp; and this loss of material, due to the crumbling of leaves, is all the more important, because the tender, friable leaves are excellent fodder, and constitute, perhaps, the very most valuable parts of the plants. In the case of clover-hay, in particular, the loss by friction is often of considerable importance, and it is always well, when harvesting hay at a very dry time, to take care that it does not become too crisp before raking, cocking and housing it. It has been said, in England, of the tedding-machine, "One great point in making hay is not to knock it about roughly when half made." In a German experiment reported by Wolff more than 7 % of the dry matter of lucern-hay was lost during the process of curing the hay in the field, and this hay was found to be less digestible than a sample of the hay made at the same time by a careful process of drying. The character of the two samples of hay will be seen in the following table: —

In terms of per cents.	The composition of the hay was		There was digested of the hay	
	When dried carefully.	When made in the field.	Dried carefully.	Made in the field.
Protein	17.00	14.94	71	67
Carbohydrates and fat .	43.80	44.22	66	62
Fibre (cellulose) . .	31.81	33.90	48	45
Ash	7.39	6.94	29	23

Then again, if grass be mown when it is fully ripe, much nutriment will be lost in the form of seeds. Timothy in particular yields many seeds which are highly charged with nutritive matters. But many of these seeds shake out from the dry husks; mice are fond of them, and not a few escape mastication and digestion when the hay is eaten by animals. Hence a tendency on the part of some people to entertain the not wholly justifiable opinion that grasses may really yield more and better hay when mown in blossom, than if left to become more mature. Though it is true, of course, that when grass is mown before complete maturity, the process of after-ripening may bring many of its seeds to perfection. It has been said, for example, perhaps rather too emphatically, by a Connecticut farmer, that the best time for cutting red-top for seed is when the grass is in blossom, since (as he believed) the seeds will fully ripen in the barn.

The Aroma of Hay.

The loss of aroma from hay during the process of making is a point of some importance. All those volatile matters escaping from new-mown hay, which are so agreeable to our sense of smell, are of course lost from the crop, and this loss might be serious if it were allowed to go on indefinitely. This aroma seems to be agreeable to cattle, in that the presence of it makes the hay more palatable. Other things being equal, sweet-smelling hay will be readily salable. Hence those processes of curing hay which tend to retain the aroma are in so far commendable.

It should be understood that the aromatic matters which escape during the making of hay do not volatilize of themselves to any great extent, in the sense that alcohol, ether or water would evaporate from an open dish. They are in reality lifted, as it were, and transported by the vapor of water as it escapes from the grass. Hence one great harm that ensues when partially cured hay is wet with rain, or fog, or dew. By the evaporation of this new and extraneous water, just so much more of the aromatic matters are carried off. A familiar example of this transporting power of aqueous vapor is seen in the freshness and sweetness of the early summer morning. When the sun begins to dissipate the dew that has fallen during the night upon the surfaces of sweet-smelling flowers and leaves, there is a movement of perfumes in the air such as seldom occurs at noonday. So, too, the peculiar odor emitted by loam, especially after a short, warm shower in the summer, is

due to an odoriferous organic substance which is lifted by the vapor of water as it leaves the soil. It is to avoid the lifting power of dew, as well as to guard against loss of heat by radiation and from contact with the cold night-air, that half-cured hay is raked up before night into windrows or cocks, in such manner that no more than a comparatively small surface of it shall be directly exposed to the weather. Here is one reason among many why hay-caps are used by careful farmers.

Chemically considered, the aromatic matters are probably essential oils, perhaps of no direct value whatsoever as food, excepting in so far as they give flavor to the hay, to make it palatable, and act after the manner of relishes to help digestion. In England the farmers often buy a condiment sold as "hay spice," which is warranted to improve all hay, and particularly to give to rough, coarse hay, or that which has been damaged, an attractive flavor and an aromatic odor. It is said that this result may be accomplished by strewing upon poor hay, as it is thrown into the mow, a small quantity of the powdered seeds of fenugreek, or, better yet, by adding to this powder a little pimento, anise, caraway and cumin. Fenugreek is used also in England for imparting an agreeable flavor to cut straw which is to be fed to store cattle with only moderate additions of roots and meal.

According to Buckman, a slight admixture of melilot-hay (Bokhara clover) will impart a highly agreeable flavor to inferior clover or grass hay. Flavorless or badly made hay may in this way be made palatable to animals, as well as by the ordinary plan of sprinkling a small quantity of powdered fenugreek-seeds over each load of the hay before placing it in the mow or stack. Both the white and the yellow melilot grow freely even on sand and gravel, but they are so highly flavored that, taken by themselves, most animals refuse to eat them freely. Hence a double gain on mixing melilot-hay with straw or flavorless hay.

Fading of Hay.

The color and the appearance of hay need to be considered, particularly when the hay is to be sold as such. For the sake of its appearance merely, it may sometimes be desirable to dry grass gradually, to expose it to direct sunlight as little as may be practicable, and in general to proceed in such wise that the hay shall be of handsome green color, and of the same bright tint throughout. If new-mown grass were left to lie too long in hot sunlight,

without turning, part of it would become brown and withered, while the rest would not, and it would then be wellnigh impossible to get the best-looking hay. Hence it is held to be bad practice to scorch hay, or, in other words, to leave it too long unturned in the hot sun.

The change of color by the action of sunlight is a mere matter of fading, just as a colored cloth would fade when exposed to sunlight; and it should be borne in mind that nothing fades clothes more rapidly than alternate rain and sun. In the old methods of bleaching cotton or linen, the practice was to spread the cloths upon a grass-field, to keep them moistened, and to turn them frequently in order to promote the chemical changes upon which bleaching depends. It is important, therefore, to avoid dew and rain, as well as too much sunlight, when the intention is to get green-colored hay.

From chemical considerations, it is plain that these influences which work to destroy the color of grass and to remove the aromatic matters would tend to destroy some of the nutritive constituents also. Hence it would appear that green-colored and sweet-smelling hay is really the best possible hay, and that these attributes may well be regarded as indicating the highest standard of excellence.

The liability of organic matters to undergo change in sunlight is well illustrated by a case somewhat analogous to that of hay; the case, namely, where herbs are cured for medicinal uses. All are agreed that herbs are best cured in the shade, and that strong sunlight should not be allowed to fall upon them. But if the sun's light and heat can bring about changes in the medicinal principles of herbs, it is fair to infer that the nutritive constituents of other vegetables are liable to suffer in like manner. This tenet that direct sunlight should be avoided consists very well with the dictum that hay should be simply dried grass, and would seem to be reasonable enough in itself, if only it were possible for the farmer to control the weather in haying time so that he could cure the crop at his leisure.

Curing of Hay in Cocks.

It is in part, perhaps, with the view of retaining the aroma and fine appearance of hay, that many persons have urged that it is best not to spread or turn hay in the field any more than is absolutely necessary, but to cure the mown grass in swaths, windrows

and cocks, at least for the most part. There is, however, another and a much more important reason than this, which has often been urged in favor of curing grass in heaps, as will be explained directly.

Fermentation means Waste.

Beside the loss of aroma, and the change of color, and the comparatively insignificant alterations due to excessive light, it is important to recognize that considerable losses of foddering materials must necessarily occur whenever and wherever hay undergoes fermentation, or active chemical change, during the process of curing. Hence the importance of avoiding all extraneous moisture, as of rain or dew, and of not leaving accumulations of grass or half-cured hay to themselves long enough for fermentation to occur.

It is on this account, as well as because of leaching, that the repeated wetting and drying of hay during the making of it is thought to be specially detrimental. In times of frequent showers it is held to be better, as a general rule, to let half-cured hay alone, than to run the risk of meddling with it. If it is in cocks or windrows, the custom is to let it remain there untouched as long as the weather holds foul or uncertain, in spite of the imminent danger of its moulding in the heaps, in case the weather should happen to be warm. So, too, when grass is mown wet, and is then rained upon, or when rain sets in before the swaths have been spread, it is customary not to disturb the grass until the weather becomes fair. Fresh-cut grass "keeps" fresh — much as meat would keep — fairly well in cool, rainy weather, though there can hardly fail to be a considerable loss of soluble matters that are dissolved and washed out as such. When grass has dried but little, and is to all intents and purposes still alive, so much the better will the cells within it be able to resist the attacks of the fungi which cause decay. Upon dead grass, on the contrary, these organisms may develop with great rapidity when it is kept moist.

It is because of the risk of rain, and the deteriorations which are apt to be caused by wetting, that many farmers like to dry their hay as rapidly as possible. The common feeling was well expressed by one of them, who, after listening to a long debate on the question how to cure hay, remarked that, in his opinion, the main point was to get it into the barn as quickly as possible after the grass had been cut. There is indeed an old English adage "carry hay while you may" which bears witness to the universality

of this sentiment. Practically, the farmers in many localities strive nowadays to make hay as rapidly as possible by tedding the wilted grass frequently with a horse machine, which exposes it to sun and air much more effectively than could be done formerly by hand labor, and causes it to dry rapidly.

When the weather permits, hay thus tedded may be merely raked into windrows, whence it is loaded directly into the wagons. Indeed, when the weather promises to hold fair, many American farmers spend little or no time in making well formed cocks at nightfall. They simply rake the half-cured hay into large windrows or throw it into loose bunches by means of the horse rake. Next day these bunches or windrows may be rolled over to expose their under sides to sun and air; and in case it should appear that the hay still contains an occasional lock or clot which is insufficiently dried some salt may be strew upon it when it is pitched into the mow. It is to be noted in any event that the process of rapid curing may be practised more safely in our dry Western States than upon the Atlantic seaboard. But in those localities where many days of dry, fair weather may be counted upon during the haying season, this modern plan of curing hay as rapidly as possible during the hours of actual sunshine, and housing it at once, enables the farmer to dispense with much labor and to avoid serious risks.

Importance of allowing Mown Grass to Sweat.

Somewhat in opposition to the plan of making hay rapidly, many good farmers maintain that, in order to cure hay thoroughly well, the grass should be allowed to "sweat" freely while making. It is really for this purpose that the system of hay-making which depends upon the slow drying of grass in swaths, windrows, and cocks, is practised. The idea is, when mown grass is left in small heaps, the leaves will continue to transpire water, very much as they would do if the grass were still standing uncut.

So long as the grass remains alive, water will be exhaled from the pores upon the surfaces of the leaves, and water will thus be pumped out continually from the stalks of mown grass in a thoroughly natural way, much as if the grass were still standing. Whereas, if newly cut grass were spread immediately in very hot sunshine, it might happen that the leaves would speedily be scorched to such an extent that circulation of moisture within them would cease, and transpiration of moisture from their pores become

impossible. After the physiological appliances for removing water have been destroyed in this way, the moisture in the stalks can only escape by way of simple evaporation, and, as that process is necessarily slow, there would be danger of carrying to the mow hay that really continued a large amount of water in its stalks, although it might seem to be tolerably dry, to judge merely by the crispness of the leaves. In this point of view, the ideal plan of hay-making would be to spread the mown grass out thin, and let it wilt "just enough," but no more than enough, and then to put it into windrows or little cocks, so that the leaves might continue to draw moisture from the stems. Many farmers assert that hay which has been cured in this way, by being allowed to stand in the cocks two or three days, always keeps better than that made by spreading the grass.

Hot Weather is Hay Weather.

Since the transpiration of water from the leaves of plants is greatly favored by warmth, it follows necessarily that as a general rule hay will "make" much more rapidly in hot weather, even when the days are sultry and the air somewhat too highly charged with moisture, than it will make on cooler days, although the air may then be fresh and brisk, and comparatively speaking dry. In the vicinity of Boston it will often be noticed that a cool, dry, breezy day in June, with the wind blowing from the northwest, is admirably well suited for "drying off the water" from hay upon which rain has happened to fall when it was nearly dried. But it is equally evident to observation that such "drying weather"— though particularly favorable for processes of mere evaporation is not first-rate "hay-weather," because the air is not warm enough to promote the transpiration (i. e. the sweating out) of the natural water from the stalks and leaves of freshly mown grass.

Naturally enough, in trying to make hay by the process of drying slowly in swaths or in bunches, it must often happen that more or less fermentation will occur; and many farmers appear, indeed, to confound this accidental fermentation with the true sweating, and to regard it as an essential feature of the system of making hay in cocks. At all events, there are many practical men who maintain that hay which has undergone a touch of fermentation during the sweating process is sweeter and more palatable than hay which has been merely dried. Some of them have even gone so far as to question the utility of efforts which have

been made to dry grass by the application of artificial heat. The trouble seems to have been not only the undue cost of the fuel and labor expended, but that the operators strove to dry the mown grass too quickly.

Artificial Hay-making.

It would seem to be plain that, in order to get good hay, not fermentation, but a true sweating-out of moisture from the stalks should precede the process of artificial drying. Indeed, the inventor of the process of artificial drying (Mr. Gibbs) has himself insisted that his method should be applied by preference to hay which has been nearly finished in the field. There is much less difficulty, he says, in partially drying grass on the ground than there is in bringing the hay to such condition that it may be housed with safety, to say nothing of the fact, that in the earlier stages of hay-making rain does much less injury than in the later, both as regards the weight and the quality of the hay.

He argues, even in the case of a wet season, that, if every advantage be taken of temporary lulls in the rain and occasional gleams of sunshine to turn over the crop and expose fresh surfaces to the withering action of time and light, a very large proportion of the sap and natural moisture may be got rid of in the fields, and that the hay may then be finished by means of artificial heat, and be secured in good condition.

The Sweating Process.

As practised by extremists, the system of sweating is somewhat as follows: Hand-mown grass is left to lie in swaths without spreading until it is considerably wilted, or, in case the crop is very heavy, the grass is spread somewhat. While still warm, the wilted grass is raked up into cocks large enough to promote gentle "sweating," but not so large that rapid or violent fermentation may be developed, for that would be not a little dangerous in case the weather should happen to become foul. After the sweating, the rule is to open the cocks into beds, and to carry the hay to the barn as soon as it has become dry enough. No doubt excellent hay can be made by this method of so-called sweating, in which more or less fermentation is allowed to occur; and it is important for beginners to grasp the conception, for the weather may often force the farmer to resort to this process, or to some modification of it.

The importance of sweating, properly so called, i. e. of allowing

water to transpire from the leaves of mown grass until the stalks have been sucked somewhat dry, is seen most distinctly in the case of clover, which, as is generally recognized, needs to be cured more carefully than grass. If the attempt were made, in our hot American climate, to dry clover rapidly by direct exposure to sunshine, the leaves would become too crisp and brittle to be handled long before the succulent stalks were dry. Hence the importance of managing the green clover in such manner that the moisture of the stalks may have time and opportunity to transpire from the leaves. The same reasoning will apply, of course, to any specially succulent crop of grass, such as a heavy growth of timothy cut young, millet, or the like, more strongly than it would to the finer kinds of grasses. Perrault in France took pains to cure a quantity of clover on cloths and obtained 35.3 lb. of dry matter from each 100 lb. of clover which was mown when half in blossom. But he found that, through the abrasion of leaves and flowers, almost one quarter of the dry matter fell to dust, so that there really remained only 22.3 lb. of hay from 100 lb. of the green clover. He observed, furthermore, that when fed out to animals 1.5 lb. of the hay went as far as 4 lb. of the green-cut clover, but since the 1.5 lb. of hay were got from 6.7 lb. of green clover, there was an advantage of nearly 60 % in feeding out the clover green rather than when it was dry.

Some writers have held, and apparently with good reason, that the sweating and fermenting process is specially applicable for curing coarse and rough kinds of grasses. Not indeed the so-called sedges which make up the bulk of the bog-meadow hay in Massachusetts, for the sedges will bear only a very moderate amount of fermentation, and are readily spoiled, but some of the coarser kinds of grasses which grow on low meadows and yield a considerable burden of rough hay. Probably these grasses might well be put into small cocks while they were still rather green and damp, and there be allowed to sweat and ferment a little. English writers say that fenland hay, though unfit for horses, answers very well for feeding cows and sheep, especially if it is a little mow-burnt or overheated, in which event the animals drink more freely than usual. Musty hay, on the contrary, such as has been damaged by stacking it when wet with rain, is not relished by any animal. It is true always that hay which has been made and housed so hurriedly and carelessly that it has become somewhat mow-

burnt may still be good enough hay for neat cattle, though not proper for feeding to horses. Cows will often eat with avidity and thrive upon very "dusty" hay such as no careful horse-keeper would allow his animals to touch. It would seem to be plain that the roughness and coarseness of the grass might be diminished by a small touch of fermentation, and that the hay might thereby be made more palatable to cattle. But it is questionable whether there is any truth in the idea, which many people had held, that the woody fibre in coarse hay is changed and improved chemically by the fermentation, so that it is not only more palatable to stock, but actually more nutritious. In general, it may be said that the sweating process is a valuable resource for dealing with succulent hay, as well as for treating any kind of hay when the weather will not permit it to be made in the ordinary manner. But too much stress must not be laid on the necessity of actual fermentation, for there is really no need of it.

Several good Ways of making Hay.

It is well to recognize the facts that very good hay may be made by several different methods, and that the whole subject of hay-making is so dependent upon weather and climate that it is practically impossible to lay down precise rules of conduct. In the rainy uplands of Bavaria the grass is dried upon little racks, such as are used for curing bean-vines in New England; i. e. the hay is piled upon little posts with cross pegs, so that a large surface of it shall be exposed to the air. The same practice is said to prevail in Switzerland, and in many other mountainous districts in Europe, where the ordinary system of making hay on the surface of the ground would be impracticable, because of wellnigh incessant small showers that keep the land wet. In Loudon's Encyclopædia of Agriculture, there are figures of these racks as used in Sweden, and on the islands at the north of Scotland.

"Heating" of Half-cured Hay.

The warmth developed in cocks of hay as soon as fermentation begins, and which is really due to chemical action, must not be confounded with the natural warmth which is retained by the cocks and windrows into which hay that is being made by the ordinary processes is raked every afternoon. One chief object of these windrows and cocks is, that they serve to hold a good part of the warmth that is raked up, so to speak, in the half-cured hay. They hinder the hay from cooling off during the night, so that it

shall be all ready to begin to dry the moment it is spread in the morning.

Of course, if the bunches of half-dried hay are left too long unopened they will ferment, i. e. they will "heat." In a word, chemical changes will result from the action of micro-organisms, and heat will be developed. It is not easy indeed to distinguish very clearly between the natural warmth which is raked up in the hay, and the heat due to chemical changes which succeeds it, for the two kinds of heat shade into one another insensibly, and it will usually happen that chemical warmth will begin to be developed long before the natural warmth has exhaled from the cocks. It is easy enough, however, to conceive of the two sources of heat, and to hold the conceptions apart.

Utility of Hay-caps.

One advantage gained by the use of hay-caps, as applied to protect the cocks during the night, is that they hold in the raked-up warmth, and keep the hay from cooling off during the night. Thus it happens that the hay not only improves a little as to dryness during the night, but is all ready to dry rapidly when the cocks are again exposed to air and sunshine, on being opened in the morning. All this as a normal or constant benefit, let alone the advantages derived from the caps in case light rains, or even heavy rains, should fall before the cocks are again opened. The caps keep dew from settling upon the hay, moreover, and thus prevent the loss of aromatic matters that would occur if dew were to dry off from the hay. They are particularly helpful in the short days of autumn when the aftermath of cold, low-lying fields is to be made into hay.

There can be no question as to the very great merit of hay-caps when properly used. They are nothing but square pieces of stout cotton cloth, which are thrown over the cocks at nightfall. In order that the cloth may be kept in place, it has wooden pegs attached to each of its four corners; and these pegs may either be driven into the ground, or pushed into the cock itself, according as time presses or not, and according to the size of the cock and the state of the weather.

Dew brings Spores.

With regard to the exclusion of dew, it is not alone its power to carry off aroma that should be considered. When dew "falls," it must tend to carry with it any particles of solid matter that may

happen to be in the air from which it is deposited, and in this way the spores of fungi, such as would cause the hay to mould, are put upon it. Several naturalists have proved that this result does actually occur, by hanging glass jars full of ice in the fields, collecting the liquid which is deposited upon them, and examining it with the microscope. Even in ancient times it was a matter of common belief, as it is to-day in many hot countries, that flesh exposed to moonlight is specially liable to putrefy. But as is well known, dew is apt to be freely deposited upon substances exposed to the moon's rays, and with the dew come the microdemes which cause putrefaction. There is no reason for surprise therefore that animal matters moistened and "seeded" by dew should putrefy speedily as soon as the sun rises to warm them. There can be no question that many of the organisms deposited upon hay with the dew are liable to produce hurtful decomposition, especially in case the hay should remain damp, or become damp, and it is plain that the fewer of these organisms get into the hay, the better it will be for the farmer. It might readily happen, indeed, that many of the spores that fall upon dead grass, i. e. upon half-cured hay, would take root, as it were, in that situation, and grow at once, although their predecessors which had been falling continually upon the living grass might not have found there any fit abiding-place.

When hay-caps first came into use in New England they were hailed with acclamation; but they soon received a very severe check, from which they have never recovered. The price of cotton, namely, was so high during the War of the Rebellion that few people could afford either to buy it or to keep it for ordinary purposes. Hay-caps are unpopular withal among hired laborers, who deprecate their use and are apt to slight them.

In reality they cause very little extra labor or trouble, provided the ropes to which the pegs are attached are thick enough and stiff enough not to snarl. In spite of all drawbacks, it is unquestionably true that hay-caps do quickly and constantly repay their cost and the trouble of using them, especially on farms where hay is made to be sold. Of course, hay-caps, like other kinds of clothing, must be hung out to dry after they have been wet by rain, or dampened by dew, lest they should decay. Eventually, perhaps, thoroughly serviceable hay-caps may be made from wood-pulp. The first cost of such caps would be very small, but as made hitherto they are said to be almost too impermeable to air and

moisture. The very porosity of cotton cloth hinders dampness from collecting beneath it at the top of the hay-cock which it covers. It is possible perhaps that it might be well to tan cloth hay-caps, as sails are tanned in damp climates, or to treat the cloth with chemicals in some way, in order to preserve the caps from deterioration through mildew or decay.

Brown Hay.

Beside the plan of having hay undergo in the making some slight fermentation, in connection with the true sweating, there is another much more emphatic conception put in practice in the process of making brown hay, so called. This method is dependent upon decompositions that are much more than incipient; but it has nevertheless found favor in several districts, especially in countries where the weather can never be depended upon for making hay by the usual process.

In making brown hay, most of the water of the grass is driven off by the heat of fermentation, only about a third of the original moisture being dried off by sun and air in the first place. Far from seeking to bring the hay into contact with the air, the chief care in this process is to exclude air from the hay. For making brown hay, grass that has been wilted to such an extent that the leaves have shrivelled, although the stalks are still plump, is heaped up either in rather large masses, or in smaller heaps that have been trodden in such wise that the air shall be wellnigh or altogether excluded from the interior of the heap. Under these conditions fermentation soon sets in, and proceeds with a good degree of regularity. In the course of it the heap becomes very hot, often as hot as the temperature of boiling water; the hay takes on a deep brown color, and gives off an odor of caramel or burnt sugar.

Sometimes, when the weather happens to become specially favorable, the hot heap is opened into beds and the hay allowed to dry out rapidly. But ordinarily the well trodden heap of grass is covered with a six-inch layer of straw, and left to itself to become hot, and to dry out without being opened.

In this operation some of the constituents of the hay undergo the well-known fermentations which chemists distinguish as the "alcoholic," the "lactic," and the "butyric"; in other words, a considerable part of the carbohydrates in the hay, notably the sugar and the dextrin, are changed to alcohol, carbonic acid, and lactic and butyric acids, while the albuminoids are at the same time more

or less altered since they also serve as food for the support of the ferment organisms. Of course a considerable part of the nutritive matters is destroyed by these changes. Enough heat is commonly developed to destroy the organisms which caused the fermentation, and it has often been argued that the brown hay is thus protected from further decay, as of mouldiness or putrefaction. It is true, also, that the copious evolution of carbonic acid during the fermentation, and the formation of lactic acid, may serve in some measure to hinder the development of organisms which cause putrefaction.

Brown hay which has been properly prepared is greedily eaten by cattle, and is readily digested and utilized by them. It is noticeable indeed that there is a certain analogy between brown hay and black tea. Black tea is made from the same kinds of leaves as green tea, and the leaves are plucked at the same stage of their growth. But for making black tea the leaves are fermented in heaps before drying them, while for green tea the leaves are dried directly.

The real justification for making brown hay is, that the farmer becomes independent of climate, and that even very weedy grass may be saved in this way in the worst of seasons. Much labor is required, of course, in raking up and carrying the heavy green grass, and the loss of dry organic matter in making brown hay is large.

The making of brown hay is here mentioned as a matter of scientific and historic interest. Practically speaking the process is probably inferior to the somewhat analogous method of preserving grass as ensilage, either in silos or in stacks, as will be explained in another chapter. Ensilaging is undoubtedly a useful means of saving weedy grass or any kind of grass in rainy regions, in case a long-continued spell of wet weather puts off the hay harvest until there is a risk that the grass may get overripe before any chance shall occur for making it into hay by the ordinary methods of drying. For saving rowen also, in the short days of late autumn, silos may serve a highly useful purpose, especially if the weather happens to be wholly unfit for hay-making.

Dryness of Hay when stored.

Practical men attach much importance to the putting of hay in the barn at a time when it is in proper condition in respect to dryness; i. e. at a moment when it is neither too damp nor yet overdry. It is held as a tenet of faith in New England, that for mak-

ing bright, sweet and salable hay it is best to dry the grass in the field no more than is necessary for the perfect preservation of the hay in the mow. It seems to be pretty well agreed, that hay keeps best when it is put in the mow in such a condition of dryness, or rather of moistness, that, on being trodden, it will settle down upon itself into a firm, compact mass. Sometimes when hay not fully dried is stored a small proportion of it may suffer damage at the top of the mow, but it is said that even this loss may be avoided by topping off the mow, when the hay is placed in it, with a layer of straw or of inferior hay. This practice of storing hay when not fully dry, and covering it with other hay, appears to be a particular instance of the process of preserving fodder as ensilage, i. e. the process in which green fodder is packed firmly in pits and covered with weighted boards or with earth. Judging from analogy it may perhaps be true that hay stored when not fully dried can be kept better in large than in small mows.

It is said that hay which has been overdried in the field will not settle down compactly in the mow, particularly if it should happen to be coarse, but will remain comparatively loose and porous, so that air has much readier access than is desirable to the interior of the heap. So, too, the carbonic acid, which is always generated in considerable quantities in mows or stacks of new hay, will escape, perhaps more readily than might be for the best. Some farmers maintain that just as green clover will keep green when well packed in a silo from which air is excluded, so half-dried clover-hay put into a tight mow the day it is mown will keep better than if it had been cured more completely in the field before it was stored. According to the practice of Mr. Bonham of Ohio [1] the clover is mown with the machine in the morning as soon as the dew is off it, and turned and shaken up loose before noon. On an average hay-day, the hay will be dry enough to rake into windrows by one o'clock, and from that time forth every effort is directed to getting it into the mow while it is warm and dry. Care is taken not to house such hay after five o'clock in the afternoon. Unless it can be put into the barn early, it may be left in the windrows until near noon of the next day.

The sides of the mow are made tight with battens, and the half-dried hay is trodden as compactly as possible and weighted above with sheaves of wheat. According to Mr. Bonham, it is important

[1] Cited from Professor W. I. Beal's "Grasses of N. America," I, 295.

to avoid external moisture, and to carry the hay to the barn when it is warm and bright with every leaf and head still upon it. In the mow the hay becomes hot (122° F. have been noticed) at first, but is said to keep bright and sweet, and to retain a good color. It is of excellent quality, and is made with comparatively little labor and at small risk.

Instead of mowing in the early morning, the clover may be cut late in the afternoon and shaken out, and spread before ten o'clock the next morning, for dew will not blacken mown clover when the plants have not yet had time to wilt. On the other hand, such hay must not be housed after sundown, lest it become mouldy and fire-fanged through the action of micro-organisms brought by dew to the half-dried hay. Nor can hay be made in this way in a single day, unless the weather be fair. A half gallon of salt to the load of hay may be used as a precautionary measure.

It would appear that there are two dangers to be guarded against in storing hay: 1st. The possibility of too pronounced fermentation and chemical action, such as would occur in case there was too much moisture in the hay when it was put in the mow. In that event the hay would "heat" unduly, and become mouldy. 2d. Such undue expulsion of the original moisture as would waste the aromatic principles and prevent the hay from ripening properly in the mow. It is a common opinion that animals, horses in particular, will eat hay made from inferior kinds of grasses much more readily in the autumn, when it is comparatively speaking fresh, than they will in winter and spring, after it has been longer in store. As the farmers say, such hay is fairly good fodder before the sap has all gone out of it. One explanation of the use of salt in hay-making is, that it permits the hay to be stored in a duly moist condition, — moister than one might care to store it if no salt were at hand. It would appear, in general, that while hay that is fit to be housed should not feel damp to the hand, it should not by any means be dry enough to be brittle, so that it would break easily on being twisted or bent.

Some New England farmers like to pile a quantity of poor bog-meadow (sedge) hay upon their mows of English hay, with the idea that the whole of the good hay shall be compressed, and the upper surface of it be protected from air and from the condensation of moisture that is generated below during the sweating process. In this way all the hay in the mow proper is made to sweat

slowly and equably even to its uppermost layer, and the warmth of this mild fermentation, extending even to the top of the hay, expels the moisture which might otherwise condense there. In hay thus covered and compressed, the carbonic acid resulting from the fermentation would be apt to saturate the good hay completely, and hinder the fermentation from passing into an injurious form. Another advantage to be credited to the plan of topping off the mows with a layer of poor hay is to be seen in barns where many animals are kept during the winter months. The breath of the animals is of course highly charged with the vapor of water, and much of this moisture condenses upon the mows of hay, particularly near the roof of the barn, with the result that considerable quantities of hay at the tops of the mows may be spoiled by the mouldiness and the fermentations which are induced by the presence of the water. But the harm done will be much diminished in case there is a layer of straw, of sedge-hay, or of salt-marsh hay at the top of the mow to receive and absorb the condensed moisture.

It is said that in Essex County, England, grass from salt marshes is sometimes carted green, — having been mown while young and full of sap, — and built into stacks layer by layer with straw in the proportion of one load of straw to four loads of the grass. This combination is thought to make better hay than would otherwise be secured. Cases are occasionally reported where, in a similar way, clover-rowen is put into small stacks together with straw. The clover is said to heat moderately, and to impart an agreeable flavor to the straw.

Old and New Ways of Mowing.

Formerly, in the days of scythes, the ordinary method of dealing with the not very heavy crops of grass in New England was to mow very early in the morning, to spread the mown grass as soon as the dew had dried off the ground, to turn it on occasion, and to rake it up and cock it in the afternoon before dew had begun to fall. On the next day the cocks were opened into beds as soon as the ground had become dry and warm, the beds were turned at eleven o'clock or so, and the hay was carried to the barn before it had become dry enough to crumble. Many farmers dwell on the importance of housing hay tolerably early in the afternoon, while the hay is still warm with the sun's heat, so that the process of curing may go forward in the mow without interruption.

In contrast with the foregoing plan, the work is often arranged

nowadays so that fresh-cut grass, and not the nearly cured hay, shall be left in the field over night. That is to say, the grass is cut with the mowing-machine at five or six o'clock in the afternoon, or earlier, if much hay is to be cut, and left over night where it falls. Next day, by stirring it freely, it will be ready to house in the afternoon if the weather is fair. The argument is, that grass thus cut rests upon warm ground during the night, and gets the first rays of the sun in the morning, whereby dew is quickly dried off, and transpiration of moisture from the leaves is promoted. Having become somewhat wilted in this way, the grass dries rapidly in the heat of midday. Moreover, in case foul weather should set in during the night, the grass, being still green, would suffer little harm. By this plan, again, some labor in cocking and capping is saved.

Formerly, when scythes were used altogether, there was an advantage in working very early in the morning, since grass which is plump with moisture and wet with dew can be cut comparatively easily and the labor of the mower is in so far lessened; but in the case of grass that is short and leafy, dew may hinder the working of the mowing-machine, because the wet grass-leaves are apt to clog the knives. This impediment may not amount to much when the grass stands stiff and tall, but it is a serious matter when low-lying leaves are to be cut, as in the case of rowen. It is one advantage to be credited to the machine, that it gives the farmer opportunity to avoid dew altogether, and to keep clear from the injurious lifting power of that agent. Instead, therefore, of proceeding in the manner first described, the plan is modified nowadays so that the grass is cut with the machine after the dew is well off it in the morning, then turned repeatedly with a horse tedder and put into the barn before night, if the day is a good hay-day.

If everything were propitious, the work would be arranged somewhat as follows: Mow with the machine until the middle of the forenoon, then change the horses from the machine to a tedder, and go over the field three or four times therewith. If the day is fair, the hay may be housed late in the afternoon. The enormous gain in thus using machinery is palpable. Fair weather may be utilized to the utmost. Whenever there is a good hay-day, it can be put to thoroughly profitable use. The making of hay in one day in this way is common enough in Massachusetts, excepting immediately upon the sea-coast, but is none the less true that ex-

cellent weather and a not too heavy stand of grass are essential conditions to success, unless indeed the grass is overripe when cut. If the crop is heavy, or the weather damp, a second day will be needed. Both the kind of grass and the condition of ripeness at which it is cut are very important considerations. Young grass dries slowly, while that which is mature needs to be cured but little. If there is clover among the grass, the process of drying will need to be somewhat different from that proper for grass alone.

There are, in short, two or three good systematic ways of making hay, one or the other of which is to be preferred, according to circumstances. 1st. The grass may be mown in the morning, turned often to dry it as rapidly as possible, and housed before night, though in order to do this the grass-plants need to be ripe, i.e. mature. Or, 2d. The grass may be cut in the morning, turned at midday, and put into cocks before the dew falls and while the hay is still warm. On the next day the cocks will be opened into beds, which will be turned in due course. In good weather the hay will be ready for the barn early in the afternoon. Or, 3d. Mow in the late afternoon, and spread and house next day, as was said.

Composition of Grass at different Stages of Growth.

The chemical history of the growth of several of the cultivated grasses has been studied by Professor Collier, of the U. S. Department of Agriculture, as will appear from the following tables. For the sake of closer comparison, the hay is supposed to have been completely dried, at 212° F., in each instance. The samples were of timothy (Phleum pratense), taken from old fields,

AT WASHINGTON, D. C.

	Spike invisible.	Spike visible.	Before Bloom.	Early Blossom.	Full Bloom.	Early Seed.
Ash	8.68	6.41	9.82	6.04	5.66	10.53
Nitrogenous matters (= N × 6.25)	12.54	11.90	10.33	10.20	9.90	12.10
Carbohydrates	54.31	57.26	54.19	57.21	58.93	50.07
Crude cellulose	19.91	21.03	22.03	22.70	21.93	22.90
Fat, etc.	4.56	3.40	3.63	3.85	3.58	3.40
	100.00	100.00	100.00	100.00	100.00	100.00
Nitrogen	2.01	1.86	1.65	1.63	1.58	1.93
Non-albuminoid nitrogen	0.70	0.55	0.36	0.30	0.38	0.51
Per cent of the nitrogen that was in the form of non-albuminoid matters	35.00	29.50	21.80	18.40	24.00	26.40
Water in the green grass	70.70	71.90	67.50	64.90	67.20	67.80

IN NEW HAMPSHIRE.[1]

	Spike invisible.	Spike visible.	In Bloom.	After Blossom.	Early Seed.
Ash	5.19	4.73	4.57	3.88	3.20
Nitrogenous matters (= N × 6.25)	9.66	9.61	5.79	5.25	5.41
Carbohydrates	57.09	56.10	57.16	58.72	62.50
Crude cellulose	23.46	25.34	28.28	28.92	26.03
Fat, etc.	4.60	4.22	4.20	3.23	2.70
	100.00	100.00	100.00	100.00	100.00
Nitrogen	1.55	1.54	0.93	0.84	0.87
Non-albuminoid nitrogen	0.30	0.45	0.10	0.15	0.18
Per cent of the nitrogen in form of non-albuminoid matters	19.40	29.20	10.80	17.90	20.70

Other analyses of timothy reported by Mr. C. Richardson, of the U. S. Department of Agriculture, are given in the following table: —

	SPECIMENS FROM WASHINGTON, 1st Year's Growth.			
	Head out, 49 cm. high.	In Bloom, 76 cm.	After Bloom, 65 cm.	After Bloom, 75 cm.
Ash	8.58	7.16	6.52	5.63
Nitrogenous matters (= N × 6.25)	14.15	10.99	8.74	8.18
Carbohydrates	47.22	50.03	51.79	55.39
Crude cellulose	23.95	27.35	28.26	27.08
Fat, etc.	6.10	4.47	4.69	3.72
Nitrogen	2.26	1.75	1.40	1.27
Non-albuminoid nitrogen	0.39	0.51	0.25	0.15
Per cent of the nitrogen in form of non-albuminoid matters	17.30	29.10	17.90	11.30
Water in the green grass	78.56	66.75	56.63	58.86

	SPECIMENS FROM INDIANA.					FROM MARYLAND.[2]
	Head not out.	Before Bloom.	In Bloom.	After Bloom.	Early Seed.	In Bloom.
Ash	7.94	7.64	7.05	6.63	5.95	4.93
Nitrogenous matters (= N × 6.25)	10.97	7.80	5.52	5.57	4.84	7.69
Carbohydrates	49.93	52.64	52.99	53.93	60.77	52.83
Crude cellulose	29.19	29.65	32.26	31.32	24.70	30.43
Fat, etc.	1.97	2.27	2.18	2.55	3.74	4.22
Nitrogen	1.75	1.25	0.88	0.89	0.78	1.23
Non-albuminoid nitrogen	0.18	0.28	0.00	0.03	0.00	0.15

[1] The sample from New Hampshire was grown upon a much poorer soil than that from Washington, which had been liberally manured. The increase of the nitrogenous constituents in the Washington hay late in life recalls the similar fact in the case of Arendt's well fed oat plants.

[2] Grown upon a poor, old field.

Per cent of the nitrogen in form of non-albuminoid matters	10.30	22.40	0.00	3.60	0.00	12.20
Water in the green grass	70.00	67.50	64.50	56.30	53.00	64.00

It will be noticed that these analyses give comparisons of grasses which had been grown under varied conditions, and that they illustrate the familiar truth that plants grown on poor land are apt to contain less nitrogen than those grown upon soils that have been richly manured. It is also noteworthy that, while the amount of nitrogen in the samples of hay from New Hampshire and Maryland was much lower than in the hay from the highly manured land at Washington, it was lower still in the hay that came from Indiana. That this Indiana hay had in general been poorly nourished seems evident from the high percentage of cellulose and the low percentage of fat which were contained in it. The Indiana hay differed, moreover, from the other samples, in that there was no non-albuminoid matter in it when it was mature. All the nitrogenous constituents in that grass were converted into albuminoids during the process of ripening.

The results of these analyses enforce anew the lesson as to the very great influence which is exerted by soil and climate upon the development of crops, particularly as to the times and stages at which their constituents may undergo change. Analyses and digestion (artificial) experiments by Ladd, in Western New York, of mature and nearly mature timothy exhibited an increase of woody fibre, even after the time of blossoming, and a considerable diminution in the percentage of sugar, while the amount of starch increased. In the undried grass there was nearly the same percentage of albuminoids at the time of complete ripeness as at the time of blossoming; but there was a rapid diminution in the amount of water in the grass after the time of blossoming, so that, on comparing the amount of albuminoids with that of the other organic matters, it was evident that the albuminoids had really diminished between the period of bloom and of complete ripeness. Probably some of them had been reduced to the condition of amides. It was found, also, that the albuminoids in the ripe grass were less digestible than those in grass cut when in bloom. Some other examples of analyses of grasses, selected from the reports of the U. S. Agricultural Department, are given in the following tables: —

RED-TOP (AGROSTIS VULGARIS) GROWN AT WASHINGTON, D. C

	From well manured Land.							From a different Locality and poorer Soil.	
	Panicle not out.	Panicle out, but closed.	Early Bloom	Full Bloom.	Seed in Milk.	Seed hard.	Seed matured	Panicle Spreading.	Early Bloom
Ash	8.19	7.34	7.55	7.27	6.60	6.74	5.30	8.41	5.84
Nitrogenous matters (N × 6.25) . .	13.19	13.61	12.73	11.02	10.44	9.47	8.89	9.81	9.96
Carbohydrates .	53.88	54.13	54.46	56.82	60.02	58.88	61.32	57.41	58.49
Crude cellulose	20.97	20.87	21.64	22.02	19.43	20.66	21.75	20.49	20.42
Fat, etc.	3.77	4.05	3.62	2.87	3.51	4.25	2.74	3.88	5.30
Nitrogen	2.11	2.18	2.04	1.76	1.67	1.52	1.42	1.57	1.59
Non-albuminoid nitrogen . .	0.82	0.80	0.54	0.53	0.36	0.18	0.09	0.28	0.32
Per cent of the nitrogen in form of non-albuminoid matters .	38.90	36.70	26.40	30.10	21.60	11.80	6.30	17.80	20.10
Water in the green grass .	67.80	68.10	70.10	61.40	52.30	51.50	57.00	68.20	58.80

ORCHARD-GRASS (DACTYLIS GLOMERATA), FROM WASHINGTON, D. C., GOOD SOIL.

					Later Growth, near end of June.		
	Panicle not out.	Panicle closed.	Full Bloom.	After Bloom.	In Blossom.	Late Bloom.	Seed nearly ripe.
Ash	10.29	8.26	8.07	9.01	8.64	6.00	6.73
Nitrogenous matters (N × 6.25) .	15.97	10.39	9.53	8.26	12.51	8.62	7.30
Carbohydrates	50.86	55.04	53.76	52.65	50.20	57.34	57.54
Crude cellulose	18.76	23.18	25.40	27.26	24 67	24.42	25.09
Fat, etc.	4.12	3.13	3.24	2.83	3.98	3.62	3.34
Nitrogen	2.49	1.63	1.53	1.32	1.99	1.38	1.16
Non-albuminoid nitrogen	1.01	0.30	0.16	0.33	0.77	0.42	0.45
Per cent of the nitrogen in the form of non-albuminoid matters	40.60	18.40	10.50	25.00	38.70	30.40	38.80
Water in the green grass	76.80	79.30	77.30	73.50	66.90	60.20	62.30

The regularity of the increase of some of the constituents of the orchard-grass, and of the decrease of others, was very marked, both in early and in late growth. Non-albuminoid nitrogenous matters tended to disappear in middle life, and to reappear afterwards during the ripening of the seed. They are subject to great and evidently rapid changes at the time when the grass is in blossom, as will appear from the following table of several other analyses of orchard-grass from various localities, which is given more particularly to illustrate the influence which soil and climate may have upon chemical composition: —

ORCHARD-GRASS IN EARLY BLOOM.

Locality.	Ash.	Nitrog. matters (N × 6.25).	Carbohy.	Cell.	Fat, &c.	Nitrogen.	Non-alb. N.	% of N. in form of Non-alb.
Dist. Columbia .	8.64	12.51	50.20	24.67	3.98	1.99	0.77	38.7
North Carolina .	8.90	10.29	52.16	24.97	3.68	1.61	0.63	39.1
			FULL BLOOM.					
North Carolina .	7.42	9.91	56.03	23.08	3.56	1.58	0.30	19.0
Dist. Columbia .	8:07	9.53	53.76	25.40	3.24	1.53	0.16	10.5
Maine	8.02	8.74	54.80	26.05	3.39	1.40	0.36	25.7
Dist. Columbia .	6.00	8.62	57.34	24.42	3.62	1.38	0.42	30.4

Pennsylvania .	6.33	8.56	54.94	27.51	2.66	1.37	0.51	37.2
New Hampshire	8.44	8.41	54.75	24.91	3.49	1.35	0.42	30.9
Average of early bloom	8.77	11.40	51.18	24.82	3.83	1.80	0.70	33.9
Average of full bloom	7.38	8.91	55.17	25.19	3.33	1.43	0.36	25.2

From the results of numerous analyses of grasses, Professor Collier has concluded that usually, as a grass grows older, the amounts of water, ash, fat and albuminoids that are contained in it decrease, while the amounts of carbohydrates and of cellulose increase. Non-albuminoid nitrogen decreases until the time of blossoming, or just after blossoming, and subsequently increases during the formation of the seed. Many exceptions to and variations from these rules were noticed, however.

Analogy of Grass to Oats.

In general, it may be said that the character of a grass, like timothy, is really so much akin to that of oats, that in all probability one might reason correctly enough about the grass-crop from what is known of oats. It will be remembered that Arendt found that the largest rate of increase of dry matter in his oat-plants was at the time when their stalks were shooting up, and that there was another considerable gain after the time of flowering, while during the final period of ripening the gain of dry matter was very small. In like manner there is a feeling among practical men in this country that timothy-grass gains very considerably in weight after it has flowered and before the seeds have ripened. Some observers say that a crop of timothy-hay may gain as much as one-third in weight, if it be left to ripen, over what it would have yielded if it had been cut at the moment of flowering, or just before.

Other investigators have found that the oat-plant increases very much between the time when the ear first appears and the end of blossoming, the general conclusion being, that, if the crop is to be mown for hay, we can assuredly realize all there is to be gained in respect to weight if the crop be mown when the seeds are in the milk or in the dough, and that, unless the mowing is delayed until this time, or until very near this time, there will be obtained a lighter yield.

It will be remembered that, in the case of oats, there was a particularly large gain of dry organic matter at or before the time of shooting, in case the crop had been manured with easily soluble nitrogenous fertilizers, while in the presence of less active nitrogenous manures the gain tended to appear at a later period, — either

at the time of blossoming, or sometimes even later than that. It is true, however, that a considerable proportion of the increase of dry matter during the period of shooting was cellulose, pure and simple. Arendt found twice as much of this substance in a given weight of his dry oat-plants after the shooting as before. More of the other carbohydrates also were produced at the time of shooting than at any other period in the life of the plant. Nitrogenized matters were found in large proportion in the young oat-plants, and it is notorious that young grass is specially rich in nitrogen; but, as has just been said, it happened, as the plants grew older, that cellulose and carbohydrates increased more rapidly than the nitrogenous substances, i. e. during the times of shooting and flowering.

Hence the advice so often given, to mow grass at the beginning of flowering, or even before flowering, should be taken with many grains of allowance. It is true that, if grass be mown early enough, the quality of the hay may be excellent, and that a larger proportion of it will be digested than is the case with late-cut hay. But these advantages would be most clearly marked if the grass were mown before its stalks had shot up, i. e. if it were mown at a time when the yield of hay would be conspicuously small; and precisely the same kind of reasoning will apply, though perhaps somewhat less strongly, to grass cut at any stage short of practical maturity. In a trial made in 1890 at the Maine State Agricultural Station one-half of 14 plots of timothy mown on July 1st yielded 4,225 lb. of dry hay to the acre, while the other half, mown on July 18th, yielded at the rate of 5,086 lb. The early-cut hay contained a larger proportion of nitrogen than the late-cut, and 56 % of its organic matter were digested by sheep against 51 % in the late-cut hay.

Objections to cutting Grass early.

Herein lies the objection to early cutting, viz. that, though excellent for certain purposes, the crop of hay is not large enough to justify any such sacrifice of quantity to quality. It has been urged, at one time or another, that, if grass is cut when in flower, the leaves will have by that time attained very nearly their full size, that they will hold fast to the stalks, and that a good part of the nutritive matters, particularly the nitrogenous matters, which have been elaborated in the plant to form the seeds, will still remain distributed pretty evenly throughout the entire plant, i. e. in the stalks and leaves. It has been urged that, even at the time when

the first blossoms begin to appear upon timothy, no one part of the plant can as yet have been much impoverished by the movement of its constituents towards the seeds that are to be. But as bearing upon this point, it is to be remembered that Arendt noticed a very remarkable gain of nitrogen compounds just after the oat-plant had flowered; that is to say, between the actual flowering and the first stages of ripening of the seed, and it is not unreasonable to suppose that a similar result may often occur in the field when the advent of warm, moist weather at this particular moment may promote nitrification in the soil. The quantity of nitrogen assimilated by Arendt's plants after they had flowered was in fact larger than that taken in at any other period. During the time of blossoming, the percentage of nitrogen in the entire plant was lower than at any other period, because, of course, of the great amount of cellulose and carbohydrates produced just before that period. But the subsequent gain of nitrogen was so large, that the grain-bearing plants were one-third richer in nitrogen than the plants in flower.

About two-fifths of the entire nitrogen in Arendt's crop were taken in between the time of blossoming and that of partial ripeness, when the seeds, though still soft, could be shelled; and nearly two-fifths of all the organic matter of the plants were produced at that period.

The Notion that Ripe Grass is Sweet.

Stress has often been laid upon another point, suggested by what happens in the case of Indian corn and sorghum-plants as they approach maturity; viz. that the ripe stalks of grass will naturally be sweeter, and will contain more sugar, than is present in the plants at any earlier period. It has been observed that the accumulation of cane-sugar in maize-plants is uniformly progressive with the growth of the plant, after a certain period, until the grain begins to glaze or harden; and in sorghum-plants it is only when the seeds are ripe that the stalks are really rich in cane-sugar. It was a fair enough inference that some such increase of sweetness as this may occur in the other grasses; and it is not improbable that a more or less conscious appreciation of this conception may have had considerable influence in leading practical men to prefer "ripe" grass for hay. But on trying to test the accuracy of the idea, Collier was unable to satisfy himself that it is well founded. From a careful study of meadow-foxtail (Alopecurus pratensis) at

various stages of development, it appeared that sugar did not increase as the age of the grass increased. On the contrary, the amount of sugar appeared to decrease with age. So, too, Ladd found more sugar in timothy mown in full bloom than in that mown later, after seeds had been formed, but before the seeds were fully matured.

Practical Men mow late.

It will be well to consider in how far the chemical knowledge hitherto acquired in respect to grasses consists with the habits and opinions of practical men as to the best times for cutting grass. The Romans, as Loudon has set forth, mowed their meadows when the flowers of the grass had begun to fade; and until a very recent period the practice was universal to make hay very late in the season. Marshall, in his day, made the capital point that the system of late mowing was a direct inheritance from the times of common fields. When there was a common right of pasturage on all mowing-lands up to the beginning or the middle of May, the hay-crop would inevitably fall late; and when, in addition to the spring feeding, the common right of pasturage came in again the moment the hay-crop was taken off the land, it was no more than natural that the owners of the hay should let that crop stand as late as possible, in order to get the largest possible bulk, for only one crop could be cut each year.

So, too, at a later period the hay harvest would naturally be put off whenever necessity compelled the farmer to pasture his mowing-fields in the spring. Thus Arthur Young, writing of an Irish locality, where farm animals are habitually kept out at grass throughout the year, although cows are taken in of nights in the winter and fed with hay, has said, "Their hay-grounds they wish to shut up about the 25th of March, but if their hay is finished, they are obliged to be later. They mow from the 15th of July to the 15th of September, which lateness is owing to their feeding so late in the spring. The medium produce per acre is two tons and a quarter."

Towards the middle of this century, and earlier, there were farmers in the vicinity of Boston, even those whose operations were the most extensive, who made a point of beginning their haying the day after the fourth of July, or the Monday after the fourth. This remark applies to men who were accustomed to secure very large quantities of hay by means of scythes and the other hand imple-

ments of those days, and it well illustrates the old idea that time should be allowed for grass to ripen. Nowadays most hay-makers in this locality have been at work nearly a month when July sets in, and almost every one strives to mow the grass before it has wholly changed to straw.

In view of the fact that June-grass blossoms some weeks before timothy, old fields which have "run out" and become filled with it naturally need to be mown much earlier than those which have recently been laid down, and are still in good condition. It is not improbable, indeed, that the change in the time of hay-making near Boston may be due in part to a considerable depreciation in the condition of the fields, and the greater prevalence of the inferior kind of grass.

To-day many farmers speak of mowing timothy when it is "in the second blossom," i. e. at a time when the very tips of the spikes of grass are in flower. Manifestly, the term seeks to express the idea that it is best to cut the grass in late blossom, or rather after the time of flowering. In general, it would appear that the mowers wait until the bloom is practically off the grass, and until a good many seeds are in the dough.

There can be little doubt, when the chief object is to get the largest yield of merchantable hay from a given cutting of grass, that the moment to be aimed at should be that when the larger part of the grass-plants in the field are out of blossom, and their seeds have begun to mature. The ideal moment would be when the seeds are considerably developed, though still easily digestible; yet not mature enough to become apt to shake out from the ears when the hay is pitched about. In case the hay is to be used for feeding horses, it will assuredly be best not to leave the grass standing so long that many of the seeds can become indigestible during the process of after-ripening, or that the bottoms of the stalks can change to the condition of hard, unpalatable straw. Even when timothy-grass has been cut at the best possible moment, taking the whole field into consideration, many seeds will usually be destroyed by mice and insects after the hay has been stored.

The strong arguments in favor of rather late cutting are, that much more hay can then be obtained from each particular field; that the hay is more easily made, i. e. more quickly, with less labor, and at less risk; that it keeps better; and that it is excel-

lent fodder for any kind of stock, including working horses, which thrive upon overripe timothy, in spite of the small drawbacks just now alluded to. As for cows and oxen, it may be said that their powerful digestive organs are competent to utilize the seeds of timothy, and the buts of overripe stalks also. Of course it is somewhat more difficult to mow "ripe grass" than grass which has not yet begun to change into straw.

Doubtless some few farmers mow their timothy rather earlier than the majority do, i. e. they may cut it when it is actually in blossom. Indeed, several farmers, who pride themselves on making super-excellent butter to be sold at exceptionally high prices, have urged that early-cut hay is best for their purposes, since butter of excellent color and flavor is readily made from the milk of cows that are fed upon such hay. But the argument loses much of its force in view of the well-known fact that not so many pounds of butter can be got from the small crop of early-cut hay as are obtained from the larger crop of hay which has been allowed to grow towards maturity.

Maintenance of Grass-fields influenced by the Time of Mowing.

There are, of course, other considerations beside mere quantity, or even quality, of a single crop, which have their influence upon the time of cutting grass. In New England it is often desirable that the grass-lands should be kept in good condition, so that they may be mown again and again during several years, and their condition may depend, to some extent, on the time of cutting.

If grass is mown early, before the plants have spent their force in forming flowers and seeds, the chance of a good crop of rowen will be increased, and the rowen will shield the roots from the sun and keep the ground from baking. On the other hand, if grass is cut when its seeds are somewhat advanced, the roots will be subjected to a very severe strain in the dry summer weather, and, even if by chance there should be rains after the hay had been carried off, it might easily happen that the stand of grass would be less vigorous than if the grass had been cut still later. For if the crop were ripe enough to shed some seeds, the ground would be resown, and if the land were fertile enough, young grass would spring up to replace any old roots which may have perished.

This notion of reseeding the land seemed important in the eyes of our forefathers, and many of them complained bitterly, on this very account, of the absurdity of the new-fangled notion of cutting grass

early. So, too, when mowing-machines were first used, the complaint was made that they injured the fields. The fact being that the machine, by cutting much more grass than could be cut with scythes, enabled the farmer to finish haying sooner than he used to do. In the times when the farmer was compelled to leave much grass until it was overripe, his fields were continually reseeded without any effort on his part.

This fact is one well worthy of being borne in mind and of being acted upon. It teaches that the reseeding of grass-lands is not to be neglected, and it illustrates the great influence the adoption of any new method of farming may exert in directions which are wholly unexpected, and perhaps antagonistic to the real purpose of the method.

From this point of view, also, it would appear that, as regards the mowing of timothy, the true point to be aimed at must be a moment soon after flowering, when there is no great risk that the roots of the grass will be injured by exposure to sun and drought. And it is not impossible that, unless the grass can be mown at this stage, it might be better to leave it standing until some seeds are ready to fall, according to the old practice. It would seem, however, even here, that it would be better to cut the grass when in the milk, and subsequently to sow seeds expressly, at an appropriate season. No doubt much good might be done at small cost by harrowing grass-fields that show signs of having suffered from the weather, and rolling in a light dressing of seeds; and it stands to reason that, if thus much is to be done, it will be still better to spread some kind of fertilizing material upon the land before harrowing it.

Impracticability of Mowing all Fields at their Best.

But let the farmer do his best, he can never cut all his grass at that one particular stage of development which he may especially esteem. What with the weather to hinder him, and the inevitable tendency of many fields of grass to come to maturity at the same moment, he must always, if he would prosper, cut some grass very early, that is to say, earlier than he would like, and other fields later. It will not do to wait until the first field is at its best, lest other fields should be too far advanced before the first fields have been harvested. So that practically, upon almost every farm, grass does get cut at very different stages of maturity. The modern tendency is to begin haying so early that no grass shall be cut too late;

and this plan is unquestionably better than the old one, of waiting until the first field of grass upon the farm was "ripe."

It is true of orchard-grass, in particular, that it should be mown early rather than late, not only because it depreciates more seriously than almost any other kind of grass when left to stand too long, but because an excellent second crop may be obtained from it, even as early as the month of August, if the first mowing has been seasonable and the conditions are favorable for growth. Thanks to these peculiarities of orchard-grass, the farmer may find an advantage in having some fields of it, to be mown earlier and again later than his fields of timothy, though it might perhaps be inconvenient to deal with a large area of orchard-grass, because of the risk that the crop may suffer injury by becoming overripe. In other words, because of the strong necessity of mowing this grass as soon as it has become fit to be mown.

July brings Hay-weather near Boston.

It is a question whether it might not be wise, in many localities, for the farmer to pasture stock for a short time in the early spring upon such of his old mowing-fields as are best suited to bear the weight of cattle, for the express purpose of making the hay-crop of those particular fields come in late. Here at Boston, for example, it may well be possible that the old practice of beginning to make hay in July was based primarily on the probability that there will be better hay-weather in that month than in June. June is not infrequently cool and rainy in this locality, and it is seldom that any continuous hot weather occurs before the fourth of July. There is, on this account, a real advantage to be gained, on the average of years, by haying in July; and it would be well, when possible, to adjust the ripening of the crop accordingly. The spring pasturing of mowing-fields is often practised in Europe, and has been commended there as tending to check early weeds and some of the ranker kinds of grasses. Some kinds of grasses, notably orchard-grass, would readily lend themselves to this kind of husbandry.

It needs, perhaps, to be said yet again, that in many districts where high farming is practised, as in Scotland, for example, good land is seldom allowed to remain in grass more than two years. The crop of the first year is almost always the best, and after the second year there is apt to be a marked falling-off unless the land is liberally manured. Generally it is held to be more profitable to manure for grain, and to renovate the land by cultivation.

European Hay better than American.

Were it not for the summer droughts, which hamper the American farmer, it would probably be well in some localities to establish grass-fields of such character that they could be mown early and often. For where the purpose of the hay-crop is to feed cattle upon the farm, and there is no intention of selling any of it directly, it might be advantageous to cut some grass as grass, i. e. just before the flower-stalk has begun to shoot upward. When cut at that stage, or earlier, grass is specially nutritious, and if there were moisture enough in the soil new leaves would immediately spring up for the second cutting.

The moister climate of some parts of Central and Northern Europe, and the absence of fodder corn and corn-stalks there, are prominent reasons why the grass husbandry of those countries differs so decidedly from ours. European meadows often carry a considerable variety of grasses, some of which (like meadow foxtail) are fit to be mown early, and others late; while in America the farmers chiefly confine themselves to one of the most grain-like of grasses (timothy), and count upon its stalks shooting up to a good height, in spite of some dry weather as the crop approaches maturity. Although very large quantities of hay are imported nowadays by England from America, on occasion, as in years of drought, it was no easy matter to find a market for American hay in England when it was first offered for sale there. Many years ago when, after a severe drought in Europe, some cargoes of first-quality baled hay were sent by steamer from New York to Liverpool, the hay could not be sold except at a sacrifice because of its unfamiliar appearance. It has been shown indeed by the results of numerous analyses that the hay of this country does actually differ appreciably from the hay of Europe. From the following table of comparisons drawn up by Professor Collier, it will be seen that American hay usually contains a smaller amount of nitrogenous matters than the European, and a larger amount of carbohydrates. There is less cellulose also in the American hay. For the sake of closer comparison, all the analyses given in the table are of hay that has been dried completely at 212° F.

AVERAGE OF ANALYSES OF AMERICAN HAY.

	77 Analyses of Wild Grasses.	21 of Grasses from Pennsylvania.	19 of Grasses grown at Washington.	6 of Orchard Grass from various Localities.
Ash	7.90	7.95	7.44	7.38
Nitrogenous matters (= N × 6.25)	8.20	10.04	10.25	8.91
Carbohydrates	53.90	55.75	55.82	55.17
Crude cellulose	27.10	23.14	22.47	25.19
Fat, etc.	2.90	3.12	3.52	3.33
Per cent of the nitrogen in the form of non-albuminoid matter . .	34.70	30.10	18.30	25.20

AVERAGES OF EUROPEAN ANALYSES, AS GIVEN BY WOLFF.

	Hay of Medium Quality.	Good Hay.	Very good Hay.
Ash	6.30	7.23	8.24
Nitrogenous matters (= N × 6.25) .	10.74	11.32	13.77
Carbohydrates	46.53	47.84	48.93
Crude cellulose	34.09	30.69	25.77
Fat, etc.	2.34	2.92	3.29

By cutting some hay-fields very early, as was just now suggested, when the plants are still in the condition of pasture-grass, it might be possible to postpone the harvest proper on those fields to a late date, and thus to get so well started that a large proportion of the hay-fields upon the farm could be mown at the best possible season.

One objection, it should be said, to cutting timothy late, is the somewhat greater liability of the crop's "rusting" when the harvest is deferred. Near Boston, the fungus which causes the grass to rust is apt to be specially harmful rather late in the summer.

Ripe Grass dries quickly.

As has already been intimated, one palpable advantage in cutting overripe grass is that it takes comparatively little time to cure it. It has often been urged, that late-cut timothy can be made into hay very readily, because a large part of its juices have dried out of it naturally. Even in the old days of scythes and hand-rakes, farmers often "made" their late-cut hay in a single day, for there was so little moisture left in the standing grass that very little time was needed to dry this remnant off.

All this consists perfectly with the notion of backward farmers, that it is unwise to mow grass before it is "ripe," since immature grass "shrinks" enormously when made into hay. It explains, moreover, a good part of the disagreement which exists among men as to the risk of storing partially cured hay in barns, for overripe hay might be stored with perfect safety after a day's making by the old methods, while the hay from young grass might

all spoil in the mow if it were housed after precisely similar treatment.

So, too, some part of the discussion as to the comparative merits of curing hay rapidly by tedding, or slowly in swaths, windrows and cocks, doubtless depends upon the condition of the grass when cut. It was not a bad taunt that was thrown out at one of these debates, that "it costs so much labor to dry young grass by the cocking process, that the farmers who practise this system take care not to cut their grass before the second blossom." Another point to be considered at the hay-harvest is, that, in case any fields must be neglected until the grass will have had opportunity to become dead ripe, it may be good policy to choose those that stand in need of being reseeded.

Some years ago it was urged by several writers that it would be well to steam hay before feeding it out to cattle, and there are several advantages to be gained by doing so, although it is known that the albuminoid constituents of fodders are somewhat less digestible after steaming than before. The scheme was found to be too costly in practice, generally speaking, because of the labor involved in it. But it is noticeable that, if steaming were a practicable process, it would probably be best to cut the grass as late as could be done without losing too many of its seeds.

New-made Hay is Laxative.

One strong objection that works against the early cutting of hay is the tendency of hay made from immature grasses to loosen the bowels of animals that feed upon it. This fact alone precludes the use of such hay for working horses. All newly made hay has a certain laxative and weakening effect upon animals, which is deprecated by practical men. Such hay cannot be sold to the keeper of a livery stable, because, as he would say, he has no wish to soften down his horses. Horse-keepers are of opinion that this laxative quality of new hay endures until the hay has passed through a process of "sweating," which occurs in the mow.

No matter how dry the hay may be at the time when it is put in the barn, it is held that it will always "sweat" somewhat in the mow. By October the process is completed, so that the hay is fit for use, provided it was ripe enough when mown. But in the case of hay made from young grass, such as rowen, for example, some part of the medicinal quality persists; and such hay is thought to be always unfit for horses that are kept at work, since it is apt to

weaken them, to make them sweat easily, and to render them liable to stumble.

Among many conflicting statements that have been published, it is difficult to judge how mature grass must be in order that the hay made from it shall be absolutely non-medicinal. Farmers disagree very much in their opinions as to the laxative action of hay made from grass that has not flowered. Some hold that all such hay loosens the bowels as rowen does, while others maintain that timothy cut early in June, before it has shown a blossom, does not disturb the digestion of cattle as rowen does, although the animals are exceedingly fond of it, and prefer it to later-cut hay. There can be little doubt, however, that hay from grass cut in blossom, or before, is more laxative than that cut later.

As regards cows, it is not easy to see why the laxative quality of hay from immature grass might not easily be obviated. It is hardly credible, for example, that rowen-hay, fed out judiciously to animals just taken in from pasture, should loosen their bowels to an injurious extent. It seems reasonable to suppose that the laxative quality of rowen is similar to that of young, i. e. green grass; and, as everybody knows, cattle suffer from diarrhœa when first turned out to pasture in the spring. The fact is, farmers are apt to keep their rowen-hay until towards the spring, in order to give it to cows that have recently calved, and in general to refresh their cattle after the winter's campaign on old hay, and it is at that time that they notice the medicinal effect.

Blend-fodder.

The true way would seem to be to feed out the rowen in small proportion at intervals throughout the entire season, or, if there were enough of it, to accustom the cattle to it just as they are allowed to accustom themselves to green grass. It would seem, too, as if an admixture of rowen and straw, or of rowen and bog-meadow hay, might be prepared, at the moment of storing the rowen, which would serve perfectly well to replace ordinary hay in many rations. In some countries the price of labor is low enough to permit of this idea being put in practice. "Blend-fodder," as it is termed in some parts of England, is prepared methodically by carting the coarsest kinds of hay, when partially dried, and building them into stacks together with an equal quantity of dry straw, either of wheat or oats.

Indeed the work might be done in some part with machinery,

and Californian farmers have reported excellent results obtained in this way with lucern, with green corn-stalks and with green sorghum-stalks. Their plan is to lay down a four-foot layer of straw and put upon it a six-inch layer of sorghum-stalks, taking care to keep the latter a foot or more away from the sides of the heap, then another layer of straw a foot or two thick and a new layer of sorghum, and so on until the mow is filled. It was noticed when fodder-corn was stored in this way that the straw was pressed down so tightly by it that more straw was actually stored in the mow than could have been put there without the corn-stalks. Blend-fodder thus prepared was preserved in excellent condition, and was eaten up clean by cattle.

It is noticeable, when the mixture of grass and grain-stubble, on fields which have been sown both with grain and grass-seeds, is mown at so late a period after the grain has been reaped, that no more than a third or so of the hay-crop as put into the barn is old dead grain stubble, that cattle will leave uneaten from a third to a half of the stubble-stalks. But when such fields are mown early, the hay, etc., obtained will be eaten up so clean that it is difficult to find in the cribs any stalks of the stubble, although the proportion of stubble in the hay will be larger in this case than if the field had been mown later, when there would have been time for more grass to have grown.

The easy digestibility of young hay is, of course, one strong point in its favor. It is curious that there should be any hesitancy about admitting the great value of early-cut hay, when there is absolutely no difference of opinion as to the supreme merit of young grass. Most farmers believe in all sincerity that there is no food, or mixture of foods, upon which cattle will thrive so rapidly as upon good pasture-grass.

Sweating of Hay in the Mow.

The so-called sweating, which newly made hay undergoes in the mow or stack, and which is thought by practical men greatly to improve the quality of the hay, at least for feeding working-horses, is a mild form of fermentation, which has been studied in England by Percy Frankland and Jordan. They find that the change which the hay undergoes is not a mere matter of oxidation by air, but a true fermentation, dependent on the action of living micro-organisms. It was found by these chemists that very considerable quantities of carbon and of nitrogen go off from the hay in the form of

carbonic acid and of free nitrogen-gas during this slow fermentation. Their newly dried hay absorbed much oxygen, even at the ordinary temperature of the air, and gave off a great deal of carbonic acid and nitrogen, though the evolution was more rapid as the temperature increased.

Moreover, after the oxygen of the air, which was at first in contact with the hay, had been used up, much carbonic acid, though comparatively little nitrogen, was still given off, as a result of the decomposition of oxygen compounds in the hay. That is to say, even in the absence of air, the fermentation went forward through the destruction of certain constituents of the hay which contain oxygen in combination.

It would seem to follow from this experience that the common practical rule, that the construction of a hay-barn should be as open as possible, for the purpose of drying as well as of preserving the hay, must depend primarily upon the power of keeping the hay cool which the open construction gives. The object of the openness is to hinder the accumulation of the heat generated during the act of fermentation, and so to prevent the occurrence of injurious fermentations of other kinds than the simple normal "sweating" of the hay.

When barns were first introduced into England, the objection was made that hay is more apt to "heat" in barns than in stacks. So, too, in building stacks of hay or grain, pipes or chimneys are often left at the middle, in order that the heat generated by fermentations may be readily discharged.

Frankland and Jordan found, on allowing oxygen to regain access to hay which had been deprived of it, that the evolution of nitrogen would begin anew, though somewhat less vigorously than at first, and that it would continue for several months, as well as the evolution of carbonic acid.

It is commonly held that this autumnal fermentation in the mow or stack must be allowed to run its course before hay can be safely pressed into bales for transportation, unless, indeed, the grass was overripe when mown. It is to be supposed that hay is at its best immediately after the process of ripening in the mow. Here in New England it is evident enough that horses will freely eat in late autumn the hay of several inferior kinds of grasses, such as they might reject in the spring, after it had lain in the barn over winter. Farmers seek to explain this fact of observation by saying

that "in the autumn such hay still has a considerable amount of sap in it." It was for the sake of utilizing inferior kinds of hay that various plans for steaming it and for methodically moistening it have been advocated, at one time and another.

"*Shrinkage*" *of Grass and Hay.*

According to Loudon, the waste of grass on being dried into hay is supposed to be three parts in four, by the time it is laid on the stack; it is then further reduced by heat and evaporation to the extent of perhaps one-twentieth more in about a month. Perhaps 600 lb. of grass may finally yield 95 lb. of hay, and between this weight and 90 it continues through the winter. In case the hay is sold during the next spring or summer, perhaps enough more of its weight will be lost by exposure to sun and wind, on moving it from the stack and marketing it, to reduce the weight to 80 lb. Speaking of the damp English climate, Loudon holds that the same hay which would weigh 90 lb. if delivered in the winter after it was harvested, will weigh 80 lb. next summer. In some parts of England a "truss" of new hay is rated as weighing 60 lb., and a truss of old hay as weighing 56 lb. Perrault, in France, observed that hay lost in the barn 16% of the weight it had after having been dried in the field.

In New England, the question as to the amount of shrinkage which hay suffers when stored in barns has commonly been debated in terms of price rather than of weight. Thus, it has happened that the main point in the discussion has been obscured by considerations relating to the cost of labor expended in pitching and hauling the hay on moving it into or from the barn, and to the interest on the money which would naturally come into the farmer's hands several months earlier in the one case than in the other.

The rule has sometimes been laid down, in this sense, that about one-third the price of the hay, as it lies in the field all ready to be housed, should be added after the hay has been in the barn for two or three months. Or, stated in other terms, it is held to be as well, or perhaps rather better, for the farmer to sell hay at $15 the ton from the field, than at $20 the ton next winter from the barn. It has been suggested, however, that hay which is freely salted when stored will weigh out heavier in the winter than would be the case if no salt were used. The result may be due in part to the tendency of the salt to attract moisture, and

so hinder the hay from drying off unduly; or it may depend somewhat on the salt's having checked the process of sweating or fermentation, which even the driest of hay undergoes when first placed in the mow.

According to a writer in the Rural New Yorker, experiments have been made in this country, extending through three years, to determine accurately the shrinkage of hay. Seventeen different lots of mixed clover and timothy hay, obtained from grass cut at different stages of growth, from the time it began to head until it was nearly dead-ripe, were weighed when put in the barn, and again in December, or later in the winter. In some instances the parcels of hay weighed two tons, and in others 800 lb. each. The largest observed shrinkage in weight was 36%, and in four separate parcels it was over 30%, while the least amount of shrinkage was 12%, in the case of very ripe clover. The average shrinkage was a trifle more than 24%. Whence it appears that hay grown for sale needs to advance not a little in price in order that it shall be worth the farmer's while to winter it.

Contrary to a popular opinion which prevails in some localities, it is to be presumed that it would not be well, as a general rule, to keep hay in the barn until the second winter, for chemists long ago detected an appreciable diminution of the nitrogen in hay that has been kept more than a year. Even after the completion of the process of "ripening," which occurs soon after hay has been put in the mow, there will naturally be a slow but constant loss of nutritive matters, either through ferment action, or perhaps by a process of gradual chemical oxidation.

Many years ago Boussingault showed that an animal fed on a given weight of recently made hay did as well as when fed on a corresponding weight of the grass from which the hay had been made, and this conclusion has been verified by the experiments of several other scientific observers. But it is certain that no such favorable result as this could be got on using hay that had been kept two years in a barn.

Other Grasses than Timothy.

If space permitted, much might be said about the various kinds of grasses that are cultivated abroad, or which might be cultivated here, instead of timothy, on soils that are ill-suited for that particular kind of grass. The great merit of timothy is that, under favorable conditions, it yields a very large crop, — a very much larger

crop than any of the other grasses of equally good quality, with the single exception of orchard-grass. Werner, in his "Futterbau," gives the yield in kilograms per hectare of good land of what may be called really good crops of a large number of grasses and clovers. The following items have been selected from Werner's table. From a hectare (= 2.5 acres) of land, there are produced of the specified grasses, on the average, the following number of kilos (one kilo = 2.2 lb.) of air-dried hay: —

The best kinds of Poa, such as June-grass and rough-stalked meadow-grass (Poa pratensis and trivialis)	5,000
Perennial ray-grass (Lolium)	6,000
Meadow-foxtail (Alopecurus pratensis)	7,700
French ray-grass (Avena elatior)	8,400
Italian ray-grass, on irrigated meadows	10,300
Timothy (Phleum pratense)	10,600
Orchard-grass (Dactylis glomerata)	15,300
The great Festuca (F. gigantea)	13,800
Ribbon or reed-canary grass (Phalaris)	15,600
Red clover	6,000
Swedish clover	4,500
White clover	2,500
Lupines	5,000
Vetches	4,000
Lucern	8,000

Reducing some of these figures to terms of pounds to the acre, we have as a good European yield of

Timothy	9,300 lb.
Foxtail	6,800 "
French ray-grass	7,400 "
June-grass	4,400 "
Vernal grass	2,100 "
Orchard-grass	13,464 "

At the end of the last century Arthur Young estimated that the best mowing-fields in England produced, at two mowings, 5 long tons of hay per acre per annum. Aftermath is included, of course, in the above estimates, and the large amount of orchard-grass, as here given must depend in good measure upon the second, or even upon a third crop. Perhaps the timothy-crop included clover.

Merits of Orchard-grass.

Timothy loves a deep, rich, light loam, plenty of sunlight, and a fair share of moisture, while orchard-grass will bear shade very well, and will continue for years to give excellent crops, even be-

neath large apple-trees. Orchard-grass has other advantages over timothy, in that it bears pasturing very well, i. e. it can withstand the biting of cattle; and when young it is esteemed by them highly. Since it blossoms earlier than timothy, and at about the same time as red clover, it is said to be better suited than timothy to be sown with clover for hay; it is a deep-rooted plant, withal, robust and vigorous as to its habit of growth. Hence it recovers quickly after having been mown, and throws out new leaves, which not only ensure a good crop of rowen, but smother many weeds, even when the grass-seed has been sown on very foul land. Moreover, the fact that it is mown very early in the season hinders several of the worst grass-weeds — such as the ox-eye daisy and the buttercup — from ripening many of their seeds among it. I have noticed that even the wild carrot finds considerable difficulty in coping with orchard-grass on poor, dry land, though chicory thrives in fields of orchard-grass.

Orchard-grass grows most freely upon good, deep soils, but it is none the less true that, economically speaking, the proper places to sow it are in the shade of trees, and on rather inferior land, for it will succeed fairly well on soils so dry as to be unfit for growing timothy. It should be mown rather early, since the hay made after the grass has flowered is, comparatively speaking, harsh or rough, and consequently of inferior quality. In the climate of Boston, this necessity of early mowing is a serious objection to the cultivation of orchard-grass, not only because grass mown early in the season dries slowly, but because the weather is apt to be rainy or showery at the time when the fields of orchard-grass are ready for the hay-makers. Perhaps this difficulty might be obviated by mowing the grass very early, and using it as grass in cases where there were cows to be soiled, or where circumstances might permit the use of grass ensilage. A second mowing in midsummer might still yield a crop of "hay," if the land were not too dry. The rapid growth of orchard-grass, i. e. its rapid recovery after it has been mown, and its power of resisting drought, are other advantages in its favor. It does better on clayey land than timothy, and it has been said of it that it loves a clayey loam, while timothy prefers a sandy loam. The habit of orchard-grass to grow in tufts is inconvenient for the hay-maker, in that the teeth of the horse-rake are apt to catch in these tussocks, to the injury of the implement and the annoyance of men and animals.

In sowing orchard-grass, it is important that the land should be fairly well charged with moisture. Its seeds differ considerably from those of most other grasses, in that they do not absorb moisture readily from dry land, and in that they may fail to germinate in case there should happen to be any deficiency of moisture in the soil. On account of this peculiarity, the seed should be bushed in or even harrowed in, and it is specially important to roll the land firmly after sowing orchard-grass. Some farmers even moisten the seed before sowing it, i. e. they spread the seed on a floor and sprinkle it with water a day or two before sowing it.

French ray-grass, sometimes called tall oat-grass, which has been occasionally grown together with orchard-grass in this country, is said to do well in Europe upon sandy loams that are neither too wet nor too dry. It is not recommended in this country as a grass to be grown by itself.

Clover and Timothy.

Probably the different times of blossoming of clover and timothy is a prominent reason why clover-hay is less highly esteemed than it should be in some parts of New England. In order to get the utmost advantage from clover, it should be mown before it has gone to seed. But where clover and timothy are grown together, as is the usual practice in this country, if the farmer were to cut the clover when at its best, the timothy would still be so young and green that the total crop would be comparatively light. Hence, he ordinarily lets the timothy come to maturity, and the clover suffer hurt from getting to be overripe. There would be less cause for complaint against clover-hay if only the clover-plant were treated fairly. Even in the best clover regions of Europe, timothy is esteemed to be a good grass to grow with clover, and it is thought that the mixture is more nourishing and more palatable than clover alone. But the mixture is there thought of and mown as clover, i. e. as clover with something admixed. It is not thought of at all as timothy with a mixture of clover.

One reason why clover is often sown with timothy in this country is that the clover, in fair seasons, will give a good aftermath, such as might not have been got if timothy had been grown by itself. It is a demerit of timothy that it does not yield a good second crop. So, too, one reason why red-top is sown with timothy is, that it forms a close sod, which persists each year after mowing, as well as permanently after the timothy has died out. It has

often been urged in Europe, that, for permanent meadows, timothy is inferior to foxtail (Alopecurus pratensis), which is a grass not much unlike timothy in appearance, because foxtail endures during many years, and because it gives a much more abundant aftermath than timothy. The foxtail has the further advantage that it blossoms a month earlier than timothy, and has a much more tender stalk. But it needs a moist situation, and cannot bear drought so well as timothy can. It is unfit for mixing with clover, since it does not come into full bearing until the fourth year, when the clover has run its course, while timothy culminates in its second year. The foxtail bears moisture better than clover, and is well suited to clay-lands and those rich in humus, and to irrigated meadows.

English Ray-grass, and Fiorin.

The ray-grass (French *ivraie*), which plays so important a part in English husbandry, is not well adapted to bear the climate of the vicinity of Boston, and even if it could withstand the cold and the droughts of New England, it would hardly be able to compete with timothy in this particular locality. In England, ray-grass is commonly sown, together with clover, in rotations where clover is an important feature. It is often sown to supplement the crop proper (clover), and serves to supply, in some part, the clover's place in case this plant should fail. Sometimes it is sown by itself, instead of clover, in order that clover shall not be grown too frequently on a given field. Moreover, the clover and ray-grass are commonly eaten upon the land by pasturing animals, notably sheep, which serve to fertilize the soil, and to prepare it for the succeeding grain-crop.

There is a coarse grass allied to red-top, called fiorin, or creeping bent-grass (Agrostis stolonifera), which seems to be a mere variety of Agrostis alba (white bent or English bent), that has often been commended by English writers for wet lands. It is held to be specially well adapted for moist, peaty soils, and for bog-meadows that are occasionally overflowed. Three tons to the acre are said to have been repeatedly obtained in England. Sinclair has said of this grass, "On mere bogs fiorin yields a great weight of herbage, and is perhaps the most useful plant that bogs can produce." The hay from it is readily eaten by horses as well as by neat cattle, but is said to be difficult to dry in the damp English climate. It is kept there in particularly small-sized stacks

on this account. Ribbon-grass is another coarse, free-growing grass, well suited for meadows that are wet with flowing water. An account of this grass, with analyses of it, and of blue joint-grass (Calamagrostis Canadensis), will be found in the Bussey Bulletin, II, 130.

In not a few localities in New England couch-grass or witch-grass (Triticum repens) has taken possession of many old fields and bottom-lands, and much of it is actually mown for hay. This grass is by no means devoid of value for the hay-farmer, and it would doubtless be esteemed were it not for the harm and annoyance caused by its creeping root-stalks when the land comes to be cultivated. Several kinds of festuca and of agrostis add to the burden of the hay harvested on most New England farms, as well as of poa, and of glyceria on low-lying fields.

Annual Weed-like Grasses.

Among grasses which specially interest the yeoman farmer, certain annuals should be mentioned which ripen in late summer, and are commonly classed as weeds. They are the false millets, called bottle-grass or panic-grass (Setaria), barnyard-grass (Panicum Crus-galli), old-witch-grass (P. Capillare), and finger-grass (Digitaria). These grasses play a not wholly unimportant part in the agriculture of New England, in that large quantities of them are eaten by sheep and store-cattle that are permitted to pasture upon the plough-land after the summer's crops have been removed.

The chief trouble with all these grasses is that they are really grain-bearing plants, which pass into the condition of straw and chaff before the farmer has had time to make up his mind about harvesting them. They grow with the weeds proper in potato-fields and corn-fields, upon stubble-fields, in hay-fields where the sod is not densely matted, and in waste places generally. The abundant seeds of the panic-grasses are much relished by birds, and domestic fowls put a good many of them to profit. Young turkeys, in particular, are said to thrive upon them. Great flights of blackbirds subsist upon them in late summer.

While standing in the fields, and especially when mature, these grasses tend to repel animals because of their rough, bristly, hairy spikes. But when converted into hay they are eaten readily enough by neat cattle and sheep. Dr. Warder, of Ohio, reports a case where the growth of bottle-grass in one of his corn-fields was so luxuriant that he mowed it and made it into hay. To his

surprise, he found in midwinter that his cattle relished this hay exceedingly. They ate it voraciously, and preferred it to timothy or to blue-grass hay. Barnyard-grass, being the largest of these volunteer crops, has naturally attracted more attention than either of the others, and not a few fields of it have been mown and made into hay, which turned out to be excellent. In some poor, sandy, though moist districts in Germany, finger-grass is cultivated for hay, and regarded as a blessing.

It will often be well for the farmer to save these autumnal, weed-like grasses, either as hay or as ensilage, when they force themselves upon him. Some persons have urged that it would be well to cultivate barnyard-grass as a forage-crop. The objection to this idea is, that a much larger amount of equally good or better fodder could be cut from a given area in the form of several of the millets; and that the yield of nutritive matter obtainable from it on good land would undoubtedly be less than could be got, for an equal expenditure of space and power, from other forage-crops.

There would appear to be one attribute of the barnyard-grass, however, which might give it an advantage over the millets and other competitors in some special cases. If, as seems probable, it could be sown very early in the season, — possibly even the year before the harvest, or at any odd moment when the work upon a farm was slack, — and then be left to itself until tolerably late in the season, so that it could be harvested at a time of comparative leisure, it might be regarded as one resource for lightening labor upon a short-handed farm. We are so accustomed to see it growing as a weed, in spite of manifold hindrances and difficulties, that it would not be safe to predict just how it would behave under favorable conditions, or when it would ripen if cultivated. When growing upon mere gravel, each particular stalk of barnyard-grass throws out a large number of strong shoots, and there is no doubt that much fodder could be got from it if it were possible to shave the plants off close to the earth, as pasturing sheep might do.

Highly interesting experiments might be made by trying to put these grasses to methodical use; and a similar remark would be true of many other kinds of weeds. Chemically considered, most weeds are highly charged with nutritive matters, and ways and means could doubtless readily be found out, after a little study,

of utilizing them. Processes of ensilaging would naturally suggest themselves as one resource, the more especially because applicable even late in the autumn, and because the seeds of ensilaged plants would neither be scattered about the barn floor nor yet be apt to escape digestion in the intestines of animals. In some parts of New England more or less hay made from the weeds of the arable land is saved as sheep fodder; and, in some places, the weed-hay is made into little stacks, so placed that the sheep may come to them to feed at their pleasure in severe winter weather when the ground is covered with snow.

CHAPTER XL.

PASTURES.

One fundamental conception in the minds of many New England farmers is, that the land devoted to pasturage upon any given farm should either be poor land or rocky land, or land so inaccessible that it could hardly be used for any other purpose, unless, indeed, it were left to cover itself with wood. The conception is a good one, and there are reasons why it should have special force in this region. It is true, of course, of many other countries, that there are certain situations where the land must be used for pastures if it is to be used at all. The sides of high mountains, as in Switzerland, and of many steep hills all over the world, must be so used, because, if the sod were once broken, the soil would speedily be washed away by rains.

In Europe, however, these wild pastures occur only in special localities, where they are put to use either for producing butter, cheese, or wool; and it is customary in that country to recognize another kind of rich or feeding pasture, to be used for fattening horned cattle, or for keeping working oxen or milch cows, or the choicest mutton sheep. English writers are apt to describe as inferior such pastures as will not fatten one large well-bred sheep to the acre. Pastures that will fatten a sheep but not an ox are regarded as of medium quality, while an acre of really good grazing-ground should fatten a well-bred ox. These rich pastures are usually maintained in such condition that, if cattle were kept out of them and the grass were left to grow, they might justly be regarded

as good mowing-fields. It sometimes happens, in fact, that these fields are mown and depastured alternately.

It is noteworthy that the best of the English permanent pastures are situated either upon reclaimed marshes or on bottom-lands, or upon strong clays, which are said to be all the better when well drained. Indeed, it is a matter of common belief in England, that clay-pastures yield more milk, and milk of better quality, than those on gravelly or sandy soils. Much cold clay-land there affords useful pasturage, which would require too large an expenditure of capital to permit of its being ploughed up and devoted to the production of grain. Since these clay-pastures would be injured when wet by the treading of animals, care is taken to keep them clear of heavy stock from November to May.

On the other hand, it is customary in many parts of Europe, where grass rotations prevail, to have rich temporary pastures, which are carefully seeded down to clover and ray-grass, as one shift in the regular rotation of crops. The grass-seed is often sown on barley in the spring, and care is taken not to let sheep have access to the "young seeds" during the first autumn and winter, though both young and store-cattle are even then allowed to feed upon the grass. During the next year the pasture is fit for fattening either cattle or sheep.

In the vicinity of Boston several causes conspire to prevent the formation of rich pastures. If they were to be established at all, either good low-lying land or clayey land would have to be given up to them, because the liability to drought in midsummer would prevent their formation on dry soils; and since the beef and mutton consumed in this locality are brought nowadays, for the most part, from distant regions which are, comparatively speaking, wild, either at the West or at the North, there is no longer any adequate profit to be gained in lower New England by rearing and fattening animals. But there is, nevertheless, much rough and poor land, fit for nothing but pasturage, which needs to be put to use, and the usual plan is to keep cows upon it for the production of milk or butter. So much hay is needed withal for use during the long winters, and there is so large a demand for merchantable hay, that the farmers are incited to grow hay on all land where it can be grown and harvested with advantage, rather than to establish rich feeding-pastures, such as are seen abroad. Exceptions to this general rule occur, of course, almost everywhere, and there

are localities in this country where many rich pastures are kept up; but the practice is, none the less, an exceptional one. In New England the problem is clearly how to make the most of the rough, rocky or sandy pastures,— to learn how to keep them from "running out," and how to treat them in order to obtain the largest possible profit.

Rough Pastures an Incident of Low Farming.

It may be said of these rough pastures, as contrasted with the smooth feeding-grounds of Europe, that it would be hard to find a better illustration of extensive as against intensive farming than they afford. As has been explained already, it is possible, in some situations, to obtain the largest profit by expending much labor and money upon the land for the sake of getting large crops, even at considerable cost, while in other places it will be proper to expend the least practicable amount of labor and money in order that the cost of producing whatever is produced may be kept at a very low point. In respect to their pastures, at least, most New England farmers are so circumstanced that they are compelled to manage them on a basis of low farming. It would be absurd, in a region where land is cheap and labor costly, to expend much labor upon the poorer land. But a pasture calls for very little labor. Neither the labor of planting or cultivating the land, or of harvesting a crop, has to be considered, while the merchantable products of a pasture can usually be disposed of at comparatively little cost.

It has happened in Europe that the amount of pasture-land decreased largely as the country became more densely populated. As nearly as can be made out, the proportion of pasture-land to arable land in England in the fourteenth century was as 20 to 1, though it was known, even then, that the amount of pasture had gradually been decreasing. Nowadays, the proportion of pasture to arable in Great Britain is barely 1 : 1, and until very recently the tendency for many years had been constantly towards the gradual diminution of the area of pasturage. Under the conditions that had obtained in England for a century or more until the present time, it was found to be more profitable to grow, in addition to grain, great crops of roots and clover, or the like, and to feed cattle upon these products, together with oil-cake and straw, than it would have been to pasture the animals. In illustration of this practice, the case has been cited of pasture-land of medium qual-

ity that could maintain, but not fatten, 3 or 4 sheep per year and per acre, which, on being pared and burnt and sown with rape or turnips, yielded the very first year food enough to support 10 large sheep for 16 weeks, or to fatten 12 sheep to the acre. Such land was easily kept in good heart by the manure of fattening sheep, and was made to yield salable grain-crops at frequent intervals.

Quite recently, however, grain has been imported so cheaply into England, and the cost of agricultural labor in that country has increased so decidedly, that the area of pasture-land now tends to increase, and during the last few years the increase is said to have been rapid. According to Caird, the permanent pasture of England was increased by more than two million acres, upwards of ten per cent, during the twelve years preceding 1890; while between 1870 and 1890 three million acres, equal to one-seventh of the land under rotation in that country, were added to the permanent pasture.

Only a few years since, it was argued in England that the mere straw of a good wheat or bean crop is worth nearly or quite as much for feeding animals as the whole produce of many an ordinary pasture. Of course the matter turned largely on the fact that, by keeping stock up and feeding them heavily, as was customary then in England, enormous quantities of manure were obtained, and proportionally large crops of grain were grown by means of the manure. The damp climate of England lends itself to this system of husbandry by enabling the crops to put the manure to use.

Where the supply of land is limited, and the demand for agricultural products is unlimited, it is profitable to cultivate land deeply and frequently, to manure it heavily, and to irrigate it if need be; in short, to work it to the limit of its capacity. But in the face of such conditions as these pasture-land cannot long exist, and even mowing-lands can hardly be tolerated, unless indeed their purpose is to furnish hay of superior quality for city horses and pleasure horses that are kept for hunting or riding.

Park Pastures.

It should be said, in passing, that the parks of England have always been an exception to the foregoing generalization. Large tracts of park-land are there pastured, some with sheep, some with cattle, and some indeed with deer, and this pasturing of parks is an important branch of husbandry. But it is plain that the

money thus gained is of the nature of salvage from a wreck, — the beauty and the privacy of the park are the first points to be considered. These are the crops, so to say, which the land is made to bear, and their value, like their cost, is very great. After these considerations have been satisfied, anything which can be gained from the land without interfering with its beauty or its privacy, whether by means of pasturage or in any other way, may be counted as clear gain.

It is an interesting fact withal, that much of the park-land of England is said to be of rather inferior quality; well enough suited for pasture-land indeed, in the American sense, but not so suitable for tillage as the generality of the land that is actually tilled. Advantage might be gained, no doubt, in many situations in this country, by copying some features of the English methods of managing such land, either by maintaining permanent pastures as good as theirs, or, at the least, by establishing permanent mowing-fields of suitable grasses upon light lands that are unfit for timothy, instead of reseeding them at frequent intervals, as is the custom now. On fairly good, well-moistened land, the American method of growing timothy is unquestionably a good method. But on poorer land, some system which looks to grasses of lighter yield indeed, but fitter quality, would be better. And this last-named system would be closely allied in its essential features to the method now actually practised in Europe.

Land cannot be fully used by Pasturing it.

According to Thorold Rogers, there have been times in the history of England when rich natural pastures were extremely valuable as compared with arable land. "In the Middle Ages," he says, "and indeed down to the time when winter roots and artificial grasses were generally cultivated," the demand for winter forage was so urgent that eight or ten times as much rent was paid for natural grass-lands that could be both mown and pastured as was paid for arable land. Of course there is usually one special advantage to be credited to the natural meadows in that the cost of cultivating or caring for them amounts to little or nothing. But with the introduction of clover and turnips as field-crops the relative value even of the best natural grass-land in England was greatly diminished, and it came to be said in general of land devoted to pasturage, that only a thin layer of the surface-soil is put to use, while by the deep cultivation required for roots and other hoed crops the land can be utilized to a much greater depth.

As long ago as 1694, Worlidge, writing on the enclosing of lands, urged that ten acres of land enclosed and sown with clover, turnips, rape-seed, parsley or the like, will feed as many cattle or sheep as one hundred acres of the same land would have done while it lay waste. In 1800 the English Board of Agriculture reported to Parliament that an acre of clover, tares, rape, potatoes, turnips, or cabbages will furnish at least thrice as much food as the same acre would have done had it remained in pasture of a medium quality; and, consequently, that the same extent of land would maintain at least as much stock as when in grass, beside producing every other year a valuable crop of grain; and this independently of the value of the straw, which, whether consumed as litter or as food for cattle, will add considerably to the stock of manure.

An English writer has stated this matter more in detail, as follows: Land capable of grazing 4 sheep to the acre is fit to produce under good tillage 32 bushels of wheat to the acre, every fourth year in rotation, or 64 bushels of oats, or 48 bushels of barley; and to feed in the alternate years 9 or 10 sheep per acre on rape and turnips or clover and grass. In other words, while such land could feed 16 sheep in 4 years when used as pasture, it could feed these sheep in 2 years if it were cultivated, and could yield crops of grain during the other 2 alternate years, so that the farmer would produce as much mutton in the one case as the other, and have in addition two crops of grain to sell in case the land was cultivated.

It has been urged furthermore that if this reasoning is true of the climate of England, where grass may be said to grow wellnigh continuously throughout the year, it may perhaps apply even more forcibly to colder countries. Thus it has been suggested of Sweden that inasmuch as grass cannot grow there for more than 5 or 6 months in the year, as a maximum, this particular crop can hardly represent the true capabilities of the land. Of our own country, Henry Stewart has said, "It must be a very good acre of meadow, and one of pasture, that will together support one cow for a whole year; but by the culture of fodder-crops of the right kinds, and the use of the silo for preserving these crops green and succulent through the winter, one acre may be made to support 2 or 3 head of cattle the year round; thus practically more than trebling the value of the land by the increased income from it."

Pastures a Symptom of Cheap Land.

Practically, however, the existence or non-existence of pastures in any given locality on good land will be determined largely by the price at which land is held, that is to say, on whether or not land is to be had there in abundance. Even in a country so populous as England, one result of the free admission of foreign grain has been the liberation, so to say, of much land that was formerly needed for the production of bread-crops, and it has become evident in recent years on many English farms that under present conditions "more meat can be produced at a cheaper rate on pasture-land than on arable, and that investment in stock is more safe than in the cultivation of grain."

In many localities "The increase of (pastured) stock has been great, while the expense attending the keeping of cattle and sheep is much less than that of the cultivation of grain-crops. The labor bill is considerably diminished by converting the land into pasture — no small advantage in an age of strikes." It is said that under present conditions as to land and labor in many parts of Great Britain "A larger number of live stock can be kept on pasture than on arable land, and the profits are more direct from grazing cattle and sheep than from growing grain, while the expenses are much less."

So, too, Mr. Caird, writing of Great Britain in 1886, says, "These islands are becoming every ten years less agricultural and more pastoral. In the last twenty years 3 millions of acres, nearly one-seventh of land under rotation, have been added to the permanent pasture. This change is likely to go on, as only the better class of lands can compete successfully with the products of rich and unexhausted soils now brought so cheaply to our shores. . . . As the result of lower prices (of grain), the poor clay-soils which are expensive to cultivate and meagre in yield will gradually all be laid to grass, or be planted for timber, and the poorer soils of every kind, upon which the costs of cultivation bear a high proportion to the produce, will follow the same reign of necessity. During the last 12 years the permanent pasture in England has, from this cause, been increased by more than two million acres, upwards of ten per cent."

Per contra, Mr. Little, writing in 1885, has urged that, for England, the prevailing fashion of changing arable land to pasture may readily be pushed too far, since experience teaches that more milk

and meat may be produced on mixed arable and pasture-farms than on those wholly pastoral. A certain proportion of arable land, which may vary according to circumstances, is needed in order to the best results. Instead of the proportion of two-thirds arable to one-third pasture, which formerly prevailed in certain districts, he suggests that about equal quantities of both may be better suited to existing conditions.

Soiling or Pasturage.

In many European localities, where land is costly, it has long been customary to do away with pastures altogether, and to keep cows in stall throughout the year, and to feed them during the summer upon mown clover or other green forage. Even in some parts of New England, in case a farmer should wish to establish rich pastures for his cows, it might well be asked whether it would not be better, all things considered, to "soil" the cows than to pasture them. That is to say, Would it not be best to grow great crops of rye, oats, maize, barley and sorghum, to be mown before maturity, or clover, Hungarian grass, and cow-peas, to be cut green, and fed out to the cattle in the barn, rather than to strive to maintain for them pastures equal to those of some of the moister regions of Europe.

It is evident enough that even in Europe rich pastures often depend in some measure upon tradition, not to say superstition, rather than upon fitness. Most of them have been inherited from times when artificial manures were not to be had, and when it was regarded as an essential tenet of good husbandry that land should be made to support itself. The matter is greatly complicated, moreover, with legal restrictions and old forms of leases, and incumbrances upon land, that have no earthly significance nowadays, except that they hamper the farmer and prevent him from using the land as he might like. It is probable that there are many pastures in Europe to-day that would yield a much higher profit if they were worked as hay-fields, and the hay were sent to the great cities for sale. It would be an interesting problem in practical agriculture to determine what method of keeping up the fertility of such fields would be the most economical, all things considered.

In this country, the practical conclusion seems to be that it is best, on the whole, to keep cows in wild pastures, to be supplemented in due course by the aftermath of mowing-fields, and to grow some fodder-corn to make good any lack of grass during the

droughts of midsummer. Perhaps it might be found advantageous, in some cases, not to depend wholly upon the corn-fodder, but to grow a succession of soiling-crops, in order to help out the pastures throughout the season, when need were. By this method of insurance against risks, a larger number of cattle might safely be carried through the summer in any given pasture.

In Europe, the comparative merits of feeding animals on mown clover, or the like, or of pasturing them upon rich pastures, have been not a little debated. It often happens there that the advantages of the two plans seem to be pretty evenly balanced; though it is recognized that the question has so many different bearings that it is hard to arrive at any general conclusion which shall be applicable to all cases.

Soiling is specially esteemed in countries where lucern and sainfoin thrive. Excepting some dry regions, neither of these crops is well suited for pasturing, because of the risk that animals may bloat unless the green plants have been partially wilted, or mixed with dry hay or straw before they are fed out, and also because of the danger that the plants may be killed when pastured too closely. But, wherever these vigorous plants can be grown successfully, it is easy to obtain from them large quantities of fodder, both for soiling cattle in summer and for making hay against the winter's need, and this at comparatively small cost for labor and manure. Under such conditions of soil and climate, soiling is forced upon the farmer. He has really no choice in the matter. But with plants that can be depastured the problem is less simple. Marshall has said of Central England, "Sainfoin is invariably mown every year. If it be once suffered to be eaten with stock, during the summer season, its productiveness is in a manner destroyed; it is said that it will not, in that country, ever afterwards rise to the scythe."

Financial Considerations.

Of course, there may be a considerable saving of capital in respect to land when soiling is practised, since a given number of animals can be thoroughly well maintained on a smaller area than would be needed if the cows were to be pastured; and it is equally true that a much larger quantity of milk or of milk-products can be obtained from a given area of fertile land than could be got by pasturing it. One item to be considered withal is that far less forage will be wasted when it is fed out judiciously and methodically.

Amount of Nutritive Matter from a Field when Soiled or Pastured.

One difficulty encountered in the very beginning by the scientific inquirer is to determine how much nutritive matter can be got from a given field of grass or clover by the method of pasturing, as compared with that obtainable from the same field by the method of soiling. Complications arise immediately because of the waste due to the treading of the animals, to their unequal feeding, and to their dung killing or injuring the grass where it falls. Attempts have been made to obtain approximative answers to this question by clipping young grass repeatedly during the grazing season, and weighing and analyzing the product, and also by plucking young clover-plants from one part of a field, in imitation of the feeding of cattle, and subsequently mowing the plants from an adjacent part of the field when they were in blossom. It was by operating in this way that Weiske obtained the results given in the following table: —

Red Clover.	Yield in Kilograms per Hectare.				
	Dry Substance.	Nitrogenized Matters.	Carbohydrates.	Cellulose.	Ash.
1868, plucked . .	4,126.0	1,143.1	1,943.8	666.5	372.9
1869, plucked . .	4,138.5	1,121.4	1,953.0	692.8	372.9
1868, mown 3 times	6,962.3	1,462.0	3,136.6	1,824.6	538.6
1869, mown twice and then plucked	6,614.0	945.2	3,503.4	1,752.5	413.2

The agreement between the two years is remarkably close, excepting the nitrogenized matters of the mown clover. Total product, nitrogenized matters and carbohydrates are all larger in the case of the mown clover than in that which was plucked in imitation of the pasturing of animals. In order to test the question as to the comparative digestibility of the two kinds of fodder, Weiske fed a couple of year-and-a-half old wethers, first with the mown hay and then with the plucked hay, and obtained the results given in the table. The crops of 1869 contained the following amounts of digestible matters (kilos) per hectare: —

	Plucked.	Mown twice and then plucked.
Organic matter	2,841.0	3,930.4
Nitrogenized matters . . .	876.9	599.2
Fat	135.1	156.8
Cellulose	465.3	866.0
Carbohydrates	1,363.6	2,308.4
Ash	116.0	118.2

Whence it appears that there was a larger yield of digestible

nitrogenized matters from the young clover, and a smaller yield of digestible carbohydrates and cellulose. Nitrogenized food is, as a rule, more costly than the carbohydrates; hence it would seem, at first sight, as if the superior quality of the pastured grass might more than balance the larger quantity of mown hay. This is evidently simply a matter of figuring: it could be answered by referring to the prices of nitrogenized matters and carbohydrates in any given locality. But in the computation an allowance would have to be made for the costs of mowing and carrying the green fodder, or of making the hay. Local circumstances would have to determine whether it would not be better to buy cotton-seed-meal or malt sprouts, or some other highly nitrogenous food, to mix with the mown clover, than to content one's self with the smaller gross yield of material obtained by pasturing.

It should be said that these experiments with red clover do not necessarily apply very closely to pasture-grass, which withstands the biting of cattle much better than red clover can, and which would perhaps give a larger yield of gross product when constantly cropped than red clover could.

The general conclusion drawn from these German experiments seemed to be, that, if the soil were good enough, and the conditions were sufficiently favorable to admit of mowing a field three times a year, it would be more profitable to soil cattle upon the produce of such a field than to pasture them there, while, if only two cuttings could be made in a year, the advantages of soiling might be questionable. For such fields as these there is an alternative method, which is employed in cool climates. That is to say, instead of soiling the cows, they may be tethered methodically upon the grass-land, as is often done in Denmark. In localities where cattle are tethered or soiled, fences are wholly superfluous, and are in fact unknown. Thaer estimated that, while a cow running at pasture needs twice as much land as would be sufficient to support her if she were kept in a stable and fed on green forage, 21 measures of land on which cows are methodically tethered will do as much service as 19 measures of land that are kept under the scythe.

Armsby's Experiments.

In experiments made in this country, under Armsby's direction, at the Pennsylvania station, seven plots of average pasture-sod were selected on an old lawn, that was covered with June-grass

and a liberal admixture of white clover, and these plots were clipped one at a time in rotation as often as the growth of the grass permitted. A box was attached to the lawn-mower in such wise that practically all the mown grass was collected as it came from the knives. At the close of the experiment it was thought that perhaps the grass may have been mown somewhat too frequently, and have been kept too close, to fairly represent a good pasture not overstocked. As was naturally to be expected, this very young grass was of superexcellent quality. Dried at 212° F., it contained 21 % of albuminoids and only 1 % of non-albuminoid matters, 44 % carbohydrates, 18 % of cellulose, 6 % of fat and 9 % of ash-ingredients. Up to October 30, there was obtained from one acre of land the following products, in terms of pounds: —

	Total.	Digestible.
Green grass	4,277	...
Dry substance	1,146	...
Albuminoids	239	160
Non-albuminoids	12	12
Cellulose	207	530
Carbohydrates	509	
Fat	71	41
Ash	107	...

It was observed that the rate of growth of the grass diminished rapidly as the season advanced. After the early spring growth has reached its maximum, there is a rapid falling off, which was doubtless exaggerated somewhat in this instance by dry weather in June, and possibly by too frequent clipping. The daily yield of grass was from 5 to 8 times as large in the early spring as it was in August. This result consists, of course, with the well-known fact that, in our dry climate, a pasture stocked to its full capacity in the spring would be overstocked in midsummer to such an extent that both the animals and the sod would suffer. But, since much of the early spring growth of grass would be wasted if a pasture were to be inadequately stocked at that season, many of our farmers are accustomed to grow fodder-corn, to be fed out gradually during the summer, to make good any deficiency of pasturage.

On seeking to compare the products obtainable from an acre of land, according as pasture-grass is grown upon it or a succession of soiling-crops, Armsby observed that food enough for one cow, for one day, was supplied on the average by

182 square feet of standing rye,
114 " " " clover,
202 " " " fodder-corn.

and that from

One acre of	There was obtained lb. of Milk.	Butter-fat.
Rye	2,120	84
Clover	3,098	125
Fodder-corn	1,508	65

From the amounts of the several crops actually eaten by the cows, it appeared that the relative area of each crop required was approximately: Rye, 3; Clover, 2; Fodder-corn, 3. But, since all three of these crops cannot be grown on one and the same acre of land in a single season, a two-course rotation will be needed, so that

	In the 1st Year.	In the 2d Year.
One-fifth of the land shall bear	Rye and fodder-corn.	Rye and fodder-corn.
Two-fifths " " " "	Clover and fodder-corn.	Rye.
Two-fifths " " " "	Rye.	Clover and fodder-corn.

It follows that there may be got from one acre of land, in one season,

	Milk.	Butter.
From three-fifths acre of rye	1,272 lb.	50 lb.
" two-fifths acre of clover	1,239 "	50 "
" three-fifths acre of fodder-corn .	905 "	39 "
Total from one acre	3,416 "	139 "

But an acre of pasture-grass, clipped continually up to Sept. 29, gave him 710 lb. of digestible matter, and inasmuch as his cows, when fed with the soiling-crops, consumed 0.7657 lb. of digestible matter for each lb. of milk produced, and 18.9 lb. of digestible matter for each lb. of butter-fat, it may be argued that, at the same rate, the 710 lb. of digestible matter contained in the pasture-grass from an acre would produce 927 lb. of milk and 38 lb. of butter-fat. Or, putting the figures into tabular form,

	Milk.	Butter.
One acre of the soiling-crops gave, lb. . . .	3,416	139
One acre of pasture-grass gave, lb.	927	38
Difference in favor of the soiling-crops, lb. .	2,489	101

In experiments made subsequently, the yield of milk from an acre of soiling-crops was 5,671 lb., and from an acre of pas-

turage, 1,504 lb. Here the difference in favor of the soiling-crops was 4,167 lb. To sum up: "In round numbers, we can produce from 3 to 5 times as much digestible food per acre, by means of the soiling-crops, as is produced by the pasturage."

At the Wisconsin station, an upland June-grass pasture was contrasted with green-cut clover, oats and corn-fodder, with the result that, in four months, cows produced 1,779 lb. milk and 82 lb. butter from an acre of pasturage, while they produced 4,782 lb. milk and 196 lb. butter from the soiling-crops. In the words of Professor Henry, "It is fair to state that, by soiling in summer, a certain area of land will yield double the amount of milk and butter that it will when pastured."

Soiling with Sewaged Grass.

The practice of feeding mown grass to animals is evidently at its best in places where many cuttings can be got from the fields each year. This is seen at the irrigated meadows below Edinburgh, where as many as four or five cuttings of young and succulent grass are obtained each season. There is a seven-acre meadow at another locality near Edinburgh that has produced from four cuttings sixty long tons of grass to the acre in one year; which means more than twelve tons of hay to the acre. Such grass is so rank that it has to be cut very often, or it would rot at the roots. It is to be remembered, withal, that there would be no sense in pasturing such land, even if that were practicable, since it receives already more manure than it can put to use. The droppings of animals upon such land would be worse than lost,—they would be a mere incumbrance. So with meadows that are irrigated, not with sewage, like those at Edinburgh, but with brook-water. They would often, practically speaking, be sufficiently manured by the water, and would not need the dung of the animals that were fed from them. In many cases, this dung had much better be put upon other fields. Poggendorff, in his "Landwirthschaft in Belgien," tells of some warped meadows near Ghent, where the grass is cut three times a year, yielding, in favorable seasons, four and a half tons of hay to the English acre.

In all such cases there would be special reasons why soiling would be better than pasturing. One great advantage in soiling, that is obtained in all cases, is the power it gives the farmer of dis-
buting the dung of his cattle according to his own pleasure.

When cattle are at pasture, their manure is of course scattered here and there, without any semblance of regularity. In some parts of the field, where the cattle rest in the shade or sleep at night, the land is very much overmanured, while other parts of the field get no manure at all. There is a considerable waste of manure, withal, what with the decay of the dung in full air, and the consumption of its nitrogenous constituents by insects.

Waste of Dung in Wild Pastures.

There can be no doubt that the dispersion of dung in New England pastures is a great source of waste. All experience teaches that, if ten tons of manure were to be spread upon an acre of land, they would exert a very beneficial influence upon the growth of the crop, whatever the crop might be; but if these ten tons were scattered, no matter how evenly, upon a hundred acres of land, it is to the last degree probable that no one would be able to perceive that any good came of it. A certain amount of concentration of force is needed in order to produce useful effects, whether the force comes from dung or from any other source. It is true enough that constant dropping may wear away stones, as the proverb tells us; but the mere pushing or pulling of a young child, no matter how long continued, cannot move a heavy load. And with this last illustration may fairly be compared the action of dung that has been too thinly scattered upon a field; for just as the force exerted by the child cannot overcome friction and inertia, so the too small amount of manure cannot overcome the wasting or neutralizing influences with which it is beset. Washing and leaching by rain, the decomposing action of the air and of living things, perhaps even the absorption or fixing of the fertilizing constituents by the soil itself, may all work to annul the economic action of the thinly scattered dung. Hence a large bare pasture profits very little from the dung and urine that fall upon it.

Pastures differ from Mowing-fields.

The problem, how best to manage a pasture, differs not a little from that of keeping up a mowing-field, because the treading, dunging, biting and resting of cattle have a very marked influence to favor the growth of some kinds of plants and to destroy others. Timothy, for example, which is so highly esteemed for hay, is quite unfit to be sown as a pasture-grass, because it suffers very much from the close cropping of cattle. Moreover, a very different result is sought for in pastures from what is expected of mow-

ing-fields. As has been insisted already, the young blades of grass which animals gnaw down in a pasture are much better food for them than would be the more fully developed grass of the hay-maker.

In experiments made at Hohenheim, and reported by Wolff, selected samples of grass were mown in different years, at several different stages of development, with the results given in the table: —

In 100 parts of the dry matter of grass mown on		There was contained parts of Protein.	Carbohydrates.	Fat.	Fibre.	Ash.
1874.	April 24	25.06	38.05	5.88	18.10	12.91
	May 13	16.31	52.76	5.38	17.36	8.19
	June 10	13.37	48.00	4.43	26.41	7.79
1877.	May 14	18.97	43.91	3.42	24.70	9.00
	June 9	11.16	43.27	2.74	34.88	7.95
	June 26	8.46	43.34	2.71	38.15	7.34

It was observed that the absolutely fresh grass of April 24, 1874, contained 19 % of water, and that of May 13, 22 %. The samples were thought to represent very fairly the normal grass of a rich pasture. The grass of 1877 was of luxuriant growth, and, being taller and "stemmier" than that of 1874, it tended to suppress clover and low-lying grasses.

The digestibility of the above-mentioned grasses was as follows: —

Of the several ingredients of the grass mown on		There was digested by sheep, in terms of per cents, Dry matter.	Protein.	Carbohydrates.	Fat.	Fibre.
1874.	April 24	67.90	79.13	74.93	63.40	74.97
	May 13	73.94	71.14	83.57	68.04	72.61
	June 10	68.11	69.14	75.06	61.73	65.94
1877.	May 14	65.16	73.29	75.65	65.44	79.50
	June 9	62.36	72.05	61.88	51.56	65.74
	June 26	55.37	55.51	55.66	43.29	61.07

Moreover, grass that is to be mown for hay should be of kinds which shoot up to a considerable height, and it is thought to be important to have only such kinds growing together as will come to maturity at about the same time, in order that the hay produced may be of uniform quality and duly ripe. But in a pasture, the precise opposite of all this is desirable. Low-growing kinds of grasses may often be best for grazing, and there will be needed several different varieties — some that come up early in the spring, and others that prosper best in autumn. It is well to have some kinds that mature early, some that flourish in the heat of summer,

and some that come on later. In short, the aim is to have in a pasture a succession of succulent and nutritious plants from early spring to late autumn.

Pastures may run out or run wild.

In New England the problem nowadays, and it will doubtless be the same for many years to come, is not so much to keep pastures in first-rate condition, as it is to keep them from actually running wild; and especially to subdue those that have already run wild.

There are two distinct tendencies to be seen in the pasture-lands of this region. They tend, upon the one hand, to run wild, and upon the other, to "run out." Much of the pasture-land in New England, perhaps the larger part of it, has never been really subdued. The first settlers cut down the original forest, burnt the logs and brushwood, and, after getting a crop of rye from the ashes, either left the land to itself to be pastured as long as possible, and again to be cut off and burnt when overgrown with brushwood; or, at the best, in later years the practice has been to scatter with the rye on the burnt land such grass-seed as has been shed by hay in the barn. Such seed, that is to say, as can be got by sweeping the floors of mows and hay-lofts. In this case, also, the land is used as a pasture as long as there is grass enough upon it to tempt the cattle. But, as a matter of course, bushes are apt to spring up on such land, and, in case the forest growth was hard wood, many sprouts from the half-killed stumps come up also, so that after a few years, comparatively speaking, the so-called pasture reverts to woodland, often of a very worthless sort, and has to be cut over and burned anew, like the original forest. One difficulty with which farmers have to deal is to prevent their pastures from thus running wild. But, on the other hand, in case no bushes at all should grow, pastures are still apt to "run out," as the term is. That is to say, the good grasses die out, and their place is taken by other kinds of grasses of much less value. Whether it is that the bad grasses push out the good, and take possession of the ground by mere brute force, as it were, or that the good grasses die out from lack of proper nourishment, has never been accurately determined, though the common belief is that pastures run out in this way because the land is exhausted. Doubtless the two causes above mentioned work to help each other, and a more precise statement of the matter than the one commonly

accepted would be to say, that the bad grasses get the upper hand simply because they happen to be specially well fitted to bear the combination of drought and lack of fertility which is to be found in so many old pastures. It should be said that these run-out pastures are found most frequently upon sandy or gravelly plains and hillocks. The original growth of such lands was often pine-trees, so that the land got pretty thoroughly cleared at the start, and the tendency for it to grow up to bushes was less than if it had been beset with hard-wood stumps.

"White-Top."

The bad grasses, now in question, are classed by farmers under the generic name of "white-top." They are characterized by the remarkable facility with which they run to seed; and, as is the case with many other grasses, cattle will not eat them when once they have shot up and formed seed-bearing ears. The wild oat-grass (Danthonia spicata) may be taken as the representative "white-top." It has a stem about a foot high, and it flowers in June. When this grass first appears in the spring, its leaves and stems are eaten by cattle, and it doubtless affords very fair pasturage at that time; but it resembles the grains proper in that it quickly shoots up to mere straw and seed, and, as a matter of course, it throws into the seeds most of the nourishment that was originally contained in the leaves and young stem. The seeds are comparatively speaking large, and they are extremely numerous, so that a considerable crop is really grown upon the land.

It is from its conspicuous tufts of seeds that the grass gets its popular name. Many of the seeds are so protected by beard and husks that cattle will not eat them, and in case they were eaten it is probable that the vitality of many of them would not be impaired. Moreover, it is a peculiarity of Danthonia that it carries great stores of cleistogamous seeds concealed beneath the leaf-sheaths, so that, in the aggregate, vast numbers of them fall back upon the land to keep up the stock of this peculiarly objectionable grass. Probably it is the enormous production of seeds by this grass, as well as its power of withstanding drought that enables the white-top to crowd out most other kinds of grasses from poor soils. Where the land is rich enough to permit the growth of free-growing succulent grasses, they would naturally smother the Danthonia.

No doubt, if it were economically possible to collect and steam

the dry, repellent stalks and seeds of white-top, cattle would eat and digest them readily enough, and be supported by them. But the burden of the grass is too light to permit any such practice as this to be thought of, and the only alternative is to devise methods of crowding out the white-top by " bringing in " the better grasses.

Methods of renovating Pastures.

Ploughing up the pasture and reseeding it, either with or without cultivation and manure, is one way of proceeding. It is, in fact, the first way that suggests itself to the mind of the average New Englander, and it has undoubtedly been put in practice frequently. Worlidge claimed in 1694 that, " In case so much wild land be enclosed as lieth convenient for enclosure, half the quantity of such open land being laid up to common grass, will feed more stock than the whole did before it was enclosed." Ploughing has, however, by no means approved itself to be the best way, even in those comparatively rare instances where the character of the land is such that ploughing is permissible. Upon nine tenths of our pasture-land ploughing is hardly to be thought of. Much of the land is so rocky that it cannot be ploughed at all; and in the wild bush-pastures, though it is sometimes possible to plough by means of several yoke of oxen, the cost of the operation would be out of all proportion to the gain. Even where ploughing is practicable, it would often be better to tear up the old sod with a sharp-toothed harrow, and to roll the land after seeding it or after seeding and fertilizing it.

An ingenious substitute for ploughing, which I have myself seen put in practice upon a very rocky and hilly pasture in New Hampshire, is to turn out a herd of lean swine upon the land, and to scatter thinly about the pasture Indian corn enough to keep the animals growing indeed, but very hungry. Under these conditions, the hogs root up all the grass and eat it, roots, stems and seeds; they clear the land of weeds and worms and insects, and the eggs of insects; they till it pretty thoroughly in spite of stones and rocks, and manure it somewhat, so that grass-seeds scattered upon the surface of the ground after the swine have been removed find a very good opportunity to take root and to grow. It is no discredit to this really effective method of husbandry, that it was described (invented?) at one time by Dean Swift, as a palpable absurdity.

Of course there are cases and places where the ploughing up of

a pasture is the best method of renovating it, and it may often be possible to do this methodically, as was the custom in the old grass rotations of Europe. Even in this country, our ancestors occasionally came very near the doing of this thing. In lower New Hampshire at the beginning of this century there were farmers who ploughed up every year a part of their pasture-land, and seeded it down to rye. After the rye-harvest they allowed sheep to run upon the stubble, so that the land was slightly manured; but they made the mistake of leaving the land to itself, for grass and clover to come in naturally, as was the fashion in those days. It would probably have been better to sow grass-seed with the rye, or, possibly, after the sheep, and so have made a methodical business of it. It is true, however, that for rough or poor land which is already in pasture the utility of ploughing is a very questionable matter, unless indeed the grass is pretty thoroughly run out. Generally speaking, the ploughing of any pasture which is still in fairly good condition is deprecated both by those farmers who have had most experience with pastures, and by the residents of old countries where pastures have been long kept up.

In some localities, one strong motive for ploughing pastures is to destroy moss. As Lord Bacon puts it, "Old ground, that hath been long unbroken up, gathereth mosse; and therefore husbandmen use to cure their pasture grounds, when they growe to mosse, by tilling them for a yeare or two."

It has been said by farmers of wide experience that while there may be no great difficulty in obtaining grass-sward of good quality upon rich loams, the problem is a much more difficult one on land of moderate quality, while upon strong clays as many as 12 or 15 years may elapse before the new pasture approaches in value to old grass-land.

It should be said, in parenthesis, that comparatively few Americans really know much about the maintenance of pastures. We have few traditions on the subject and very little experience. It is but a few years, comparatively speaking, since the question of improving pastures has been much discussed in this country; and it would appear that the first idea that came into men's minds was to plough, cultivate, and lay down to grass; then mow two or three years for hay, and finally revert to pasture. But, as the years roll on, the European opinion that it may be unwise ever to plough stiff, strong land that can be used for pasturage, gains strength in some of our grazing regions.

Richness of old Pastures.

It is said that the grass of the old European pastures which have never been ploughed starts earlier in the season than that of newly made pastures; that it endures later in the autumn, and that the milk from such pastures is richer, that is to say, less watery, than that from land which has been reseeded. This last item ceases, of course, to be one of advantage to the milkman, who wishes to sell milk as milk. But if the intention is to make butter or cheese, there is an advantage in the milk from old pastures, since a smaller number of quarts of such milk will make a given amount of butter or of cheese. One computation has been published, to the effect that ten quarts of old-pasture milk will make a pound of butter, while as many as thirteen quarts are required to that end when the milk is obtained from pastures that have recently been laid down. It was urged at one time, of certain pastures in Central England, that, while applications of manure increased the yield of grass, the quality of the cheese obtained from that grass was inferior. It was noticed that the cheese suffered more particularly during the first year after the manuring, and sometimes even in the second year, but that on the third year the evil effect was no longer appreciable. On this account, the farmers either mowed the grass the first year after manuring it, or they pastured it off with fatting cattle.

It should be said that a favorable climate has manifestly no little influence upon the productiveness of many noted European pastures. At the north and west of England, where the air is continually damp, even light, sandy soils support excellent pasture-grass; and such land is there found to be improved by pasturage, in that much vegetable matter accumulates in the soil. But little if any such improvement is noticed when similar soils are laid down to pasture in the comparatively dry, sandy county of Norfolk, on the east coast. That is to say, grass may succeed well in regions of constant dampness, even in situations which would be quite improper for grass if the land were to be occasionally exposed to drought.

One reason of the poverty of new-made pastures in this country appears to be that, in seeding down land to grass, we neither use the kinds of seeds best fitted for pastures, nor do we sow a sufficient variety of grasses. Timothy, red-top, and red clover may possibly be the best mixture for the majority of our mowing-fields;

but it is very certain that these plants, excepting red-top, are not well adapted for pastures. As was just now said, there is needed in pastures a great variety of grasses, some to come early and others late, and others between times; some to grow in spite of drought, and others to prosper best in rainy weather; each kind to grow in the spaces between the rest, and to feed upon what the others leave. One thing is true, at all events, viz. that it is not easy by artificial means quickly to produce such sward as is seen in good old pastures. It could be done in time, perhaps, by laying down the land as for a lawn, and then cropping the grass continually with a lawn-mower, as a preliminary to the admission of cattle. But with what difficulty, and at what a cost!

It has been remarked in England that newly made pastures should not be heavily stocked with sheep, at least not during the growing season. For the first year or two young cattle are best, until the turf has become close, and strong enough to bear the tread of an ox; meanwhile an occasional dressing of compost or of farmyard-manure will do good service. The constant cropping of sheep in a new pasture has a very injurious effect on all the finer and sweeter grasses, and only those kinds of grasses which are less liked can make head against the incessant gnawing. In cases where the land is mown at first, it is said to be good practice to top-dress it in the autumn, after the second hay-harvest, and to turn young cattle upon it the following spring. By helping the grass at the critical period of the second mowing it may be kept from falling away.

Grass needs Moisture.

It should be borne in mind, however, that, oftener than not, rich pastures depend upon humid climates, and that the farmers who practise grass rotations sow very different kinds of seeds, according as their farms are situated in wet countries or in dry. In Scotland and the west of England, where frequent rains occur throughout the summer months, perennial ray-grass affords excellent pasturage, and the sowing of it, in rotation with other crops, has been found to be an economical means of restoring fertility to land which has been somewhat fatigued by grain-crops.

In both these countries, the pasturing of ray-grass for two years on free loams is generally regarded as a safe and judicious means of promoting fertility, and the practice is often prescribed in leases on this account. Thanks to the abundant moisture, the ray-grass grows continually throughout the summer, and it tillers freely when cropped by cattle, and sends out so many fresh roots and stems that the land is closely covered with grass, weeds are excluded, and much organic

matter is stored up in the soil for the use of the crops which are to succeed the grass.

On stiff clay, however, the ray-grass suffers from the trampling of animals; much of it is killed by the puddling and poaching action of their feet, so that it seldom does well upon clays during the second year. In the drier districts of Great Britain, on the contrary, perennial ray-grass is regarded as decidedly inferior to the clovers, which produce much larger amounts of forage than it; and one reason for the maintenance of the four-course rotation on the light soils of Norfolk County is said to be that there is no good pasture-plant which can take full possession of the dry surface-soil, and maintain its growth during the heats of the summer months. If the clover-fields of Norfolk were to be pastured two years, instead of one, the land would become filled with weeds when the clover "thins out," and the condition of the land would deteriorate.

In Ireland the moist climate is eminently favorable for rich pastures, which can be maintained in excellent condition for many years, even on light land, provided the soil is in good condition when the grass-seed is sown, and that the sod is occasionally top-dressed.

Improvement of Bush-pastures.

Many farmers try to keep down their bush-pastures by going through them in August with a short scythe, the so-called bush-scythe, and subsequently burning the dry brush upon the stumps of the bushes. This is a very inefficient method, unless, indeed, the bushes are juniper or some other resinous shrub, in which event the bush-hook, or even a hatchet, axe, or bill-hook, would naturally replace the scythe. Chemically considered, the process of bush-mowing would have a certain merit if labor were cheap enough to permit of the bushes being mown or lopped when young, and saved, to be used as sheep-fodder in winter, or for making manure. As now conducted, the process is wasteful, and not particularly effective. Hardwood bushes are seldom killed by such burning, while it often happens that a good deal of the grass around them is killed. Indeed, the bushes would probably suffer more than they do now, if the cuttings were immediately raked away, so that cattle could come at the stumps and gnaw off the young sprouts at the first moment of their appearance. As a rule, it is better to knock off sprouts than to cut them off. A dull instrument, such as the head of an axe, for example, will serve much better for killing sprouts than a knife, or than the cutting edge of the axe. New sprouts do not grow so readily from a bruised surface as they do from the edges of a clean cut. (E.

Hersey.) Perhaps the very best way of killing sprouts is to overstock the pasture with sheep, so that every green thing within the enclosure shall be eaten off close, and this method is in fact employed not infrequently in New England, as will be explained directly.

In case there are but few bushes in a pasture, farmers often pull them up by the roots by means of a hook worked with a yoke of oxen, or two men work together, one to bend down the bush, while the other cuts off its roots with a grub-hoe. A harrow is then dragged over the spots where the bushes were, and a small quantity of white clover-seed is scattered, or simply the sweepings from hay-mows and lofts in barns. White clover is specially esteemed for this purpose, both because it does well in pastures and is liked by all kinds of cattle, and because a single plant will spread over a large surface, to the exclusion of weeds and spindling grasses. Moreover, in case the soil is moist enough, it may happen when the creeping clover is trodden upon and broken that each joint of the plant will throw out fresh roots. In view of the spreading habit of growth of white clover, only a very small quantity of seed is needed for an acre of land. The fact that the clover-plant may act to bring nitrogen from the air is another strong point in its favor. Some farmers sow a little rye with the grass-seed on the spots to be renovated, and let the cattle feed upon it from the first moment of its appearance. When continually headed in by the biting of animals, rye will continue to throw out leaves for a long while. Cattle are said to be better than sheep for feeding on such patches of young grass, since sheep are apt to pull up the young plants.

Rib-ploughing for renovating Pastures.

Attention has already been called, in Chapter XVII, to the possibility of applying the old English method of rib-ploughing for the improvement of pastures which have run out. In ribbing, the plough simply turns over a thin slice of sod, and consequently requires no great expenditure of labor. Not every sod is turned, but every other sod, in such manner that the turned sod shall fall face to face upon grass which has not been disturbed. Grass-seeds, clover-seeds and rye might be sown immediately upon the ribs or ridges, leaving the surface of the field uneven. By proceeding in this way upon sandy pastures and those free from stumps and stones, it would be possible to destroy the old grasses

and weeds, especially white-top, and to take a new start, at the least possible cost of labor.

It is evident enough that rough and ready methods of irrigation, and of drainage also, such as dead furrows, and even land-beds, may often be applied with advantage to pasture-land. It is impossible that there should be a good growth of nutritious grasses where stagnant water rests in or upon the soil. Some farmers have found an advantage in top-dressing their pastures with plaster of Paris, and in regions where plaster is an effective manure this method is undoubtedly a good one. Others find their advantage in top-dressing with wood-ashes, or with leached ashes, and it is to be presumed in all these cases that the bringing in of clover (and of nitrogen by the clover) is the chief gain. Other men top-dress their pastures occasionally with composts of one kind or another, especially the bare spots, or those where the grass is poor; then they harrow and scatter grass-seed, which they brush in or roll in when practicable. Sometimes they do not even harrow the land, for fear of injuring the grasses that are already there, but simply spread the manure thinly, and then scatter the seed upon it and the turf.

As against moss, which is extremely troublesome on some soils of inferior character, English writers urge the importance of harrowing freely and frequently, and, in the lack of wood-ashes, of applying composts made with lime and salt. One plan was to mix lime and salt as follows: On a layer of lime 6 inches thick spread a two-inch layer of salt, and repeat these layers three times, or until the heap is two feet high. Turn and mix the materials, and repeat the process three times at intervals of ten days, when the mixture will be ready for use. 20 bushels of salt to 40 bushels of lime is sufficient for an acre of land. The mixture may be applied either in autumn or early in the spring; "it is valuable for any agricultural purpose, and is found to suit grass-lands exceedingly well."

In discussing the permanent pastures of England, Voelcker has said: "There is no pasture the productiveness of which may not be largely increased by a heavy dressing of farmyard-manure, or by a top-dressing of guano, or by artificial mixtures of ammonia-salts or nitrate of soda and superphosphate of lime. In some cases I have also found the use of potash-salts very beneficial in conjunction with superphosphate and guano, or in combination with superphosphate and nitrate of soda. Unfortunately, the application of artificial manures to permanent pastures is often disappointing in an economical point of view. As a rule, no artificial manuring mixture gives so favorable a return as good farmyard-manure; . . . . there is no difficulty in growing roots and cereal crops economically with artificial manures; but I am not so certain that, as a rule, it will be found a

profitable undertaking to manure permanent pasture with artificial manures." It is particularly conspicuous on pasture-land that "fertilizing materials which are very soluble in water, and are not absorbed chemically and rendered insoluble by the soil, require to be used sparingly, and should always be used in showery weather, in order that they may be washed into a large body of the land."

Sheep for renovating Pastures.

All these devices are good, but perhaps the best general method of all is to overstock the pasture with sheep, as was said, no matter whether the land has run out or run wild. One plan is to have a movable fence, so that small portions of the land can be partitioned off, and to keep the sheep upon these plots until they have eaten up everything, after which the land is harrowed, if possible, and sown with grass-seed or with clover. Another plan is to keep rather more sheep in a pasture than it can carry, during several years. In either event the sheep must receive a sufficient supply of some concentrated food, such as oil-cake or grain, to make up the deficiency of the pasture, and to keep them in proper condition. The rich food has the merit, meanwhile, that it manures the land. It is a familiar proposition, in England, that by giving grazing animals grain the herbage of their pastures may be gradually improved, and even be made to yield good crops of hay.

Much good may be done to many pastures by sheep, even when there is no intention of employing an excess of them, since they are fond of many plants that neat cattle do not care for, and indeed eat with avidity and impunity many weeds which cattle dislike and avoid, notably buttercups, cowslips, whiteweed, dandelions, and other "bitter" plants. A very few sheep, kept in a pasture that is fairly well stocked with cows, will do much towards keeping down plants whose presence is undesirable. The sheep prune the pasture, as it were, and clear it up. But it is not well to have too many sheep graze together with cattle, since, from feeding so much closer than the cattle, they are able to pick out the finest of the young grasses and clovers, and so consume the very best part of the food. As the old saying goes, "Too many sheep in a pasture may keep the grass so short that an ox cannot find any of it long enough to lap his tongue around." Instead of a few sheep kept constantly, a flock of sheep may once in a while be turned into pastures that have been eaten close by neat cattle. Or, instead of that, the pasturing of cows may be made to alter-

nate year by year, or two years by two years, with the pasturing of sheep; the sheep not to be in excess in these cases, but to be supported entirely by the pasture-grass. The idea here is simply that the sheep will check much vegetation that cows do not like, and will meanwhile fertilize the soil by their droppings, which, unlike those of horned cattle, are evenly distributed.

On the other hand, a few store cattle, kept together with many sheep, might help to keep the pasture smooth, for the cattle could not rob the sheep in so far as short, sweet grass is concerned, but would be compelled to subsist on long grass, such as the sheep would neglect so long as an abundance of short grass was to be had.

There are cases on record where fields that were full of white-weed or buttercups have been completely cleared by pasturing the fields with sheep, not in excess, for a couple of years, from early spring to the last of June. Under this treatment few, if any, of the weeds ever came to flower, and they could not withstand two years of such close feeding. So, too, with rag-weed and the annual grasses that flower in late summer; sheep will eat them readily when not yet ripe, and thus prevent them from flourishing and going to seed.

It might often be good policy for the farmer to keep a few sheep merely as instruments for the clearing of pastures in this way, and for consuming weeds collected from gardens and tilled fields. The idea would be to let the sheep feed in the pastures in alternation with the cows. Much good fodder might be utilized by means of them, and a vast number of weeds and of seeds of weeds be destroyed. Sheep are specially well adapted for pasturing orchards. They manure the land evenly, and by eating windfall fruit they destroy the grubs which caused the fruit to drop. If left unmolested, these grubs would bury themselves in the ground and change to moths, in due season, for stinging the fruit of the next year. If the land beneath mature apple-trees, for example, were laid down to orchard-grass and stocked with sheep, the trees might perhaps bear more and better fruit than can be got from them by the usual method of treatment. If occasional tillage should be deemed necessary, it might be had by tearing the sod with a scarifier.

Mowing of Pastures.

Instead of changing from one kind of cattle to another from year

to year, it might possibly be well in some cases, where the land is strong and smooth, to mow the pasture once in a term of years, as if it were a hay-field, in the case of a favorable season. And this in spite of the risk, illustrated by Darwin, that the growing crop might smother some good grasses that thrive in cropped pastures. Mowing in this way might perhaps tend to favor the growth of grasses that seed very early and very late, and perhaps check those that ripen at the time of mowing. Many weeds peculiar to pastures would be checked by the mowing, while others peculiar to mowing-fields would start up, and would be eaten down in the autumn, or after the hay-harvest, when the cattle were returned to the field. One advantage incidental to the mowing would be the opportunity to view the grasses in the field, and to note what kinds were predominant.

An English writer has said, "The continual grazing or continual mowing of grass produces a special character of herbage, and I have both seen and experienced the best results from mowing, for 2 or 3 successive years, old grass-land, and grazing for a similar period meadow-land which had been annually mown for a long series of years. Many of the coarse grasses and weeds peculiar to fields annually mown are destroyed by a few years' grazing, and the weeds that will sometimes infest grazing-pastures are likewise destroyed by mowing, and the patchy appearance of the fields corrected."

Others have said, "Occasionally we mow some of our grass-land which has the thinnest sward, the seeds from the hay having a tendency to improve the pasture, though the improvement is probably not entirely due to the seeding of the land." "If, in spite of the purchased food consumed by stock on a pasture, I find that it is not grazing well, I apply a little salt, manure it, and mow for a year or two, which quite changes the herbage, and improves the field immensely."

In view of the familiar fact that many plants can grow fairly well in the shade cast by other plants — as is seen constantly in groves and in tracts of young woodland — the question may well be asked whether it might not, perhaps, be possible to find out, and to grow together purposely, a mixture of tall and of low-lying grasses, which should yield a paying crop of hay when mown early in the summer, and subsequently afford good pasturage during the remainder of the season. A method of procedure such as this might be advantageous in some localities.

"*Followers*" *in Pastures.*

In some localities, where the climate favors the practice, it is customary to change the animals from one pasture to another, in such wise that there shall always be one field in good case for the milch cows or fatting cattle. After these more important animals

have eaten the grass tolerably close, they are changed to a field that has been at rest, and young cattle are turned into the field which the cows have left, and finally sheep may succeed the young cattle.

This idea of "followers" in pastures is an old idea, and it is an excellent one. In many districts in England it is customary to buy lean Scotch cattle in autumn to clear up the pastures at the time when the heavier cattle are turned into the aftermath of the mowing-fields. A somewhat similar practice prevails in Eastern Massachusetts, in years when the summer has been moist enough to keep up a good supply of grass. Store cattle are bought in September, and turned into the pastures, and stubble and mowing-fields, where they not only put much good grass to profit, and vast numbers of weeds also, but, after the frosty nights have come, they consume great quantities of grass that had previously been unpalatable to stock. It has been said of the Midland Counties of England, that "It is a great point with the grazier to have the land completely cleared of fog or old grass by November, every tuft and rough bunch eaten down completely bare, and all sour and unpalatable patches mown so that the growth of weeds and rank grasses may be discouraged, and the pastures gradually improved."

Whenever there are not enough animals kept in a pasture to eat off the herbage close, many tufts of grass will grow rank and tall, especially where dung or urine has fallen, and much grass may even go to seed. All such tall grass is avoided by cattle until the advent of frosty nights. But after it has been touched by frost, the rank grass is sweetened, as the saying is, and then animals will eat it readily. The practices above mentioned depend not only on the immediate economy of putting all available herbage to use, but in part doubtless upon an old belief of English graziers, that it is good for a pasture to be eaten off very close not infrequently, and particularly in early summer. One of them (Mr. Turnbull) has said, "I keep pastures well eaten down, believing that grass contains more nutriment when it first springs than at any other stage of growth." There is little reason to doubt the correctness of this view, since the close feeding would tend to the production of a fine, close, even turf, such as all experience teaches is excellent for cattle, while it would prevent any tufts of grass from growing up tall and becoming unpalatable. In some parts

of England rough pastures are often greatly improved by grazing them close with ewes in winter, when the animals are receiving dry food. Nevertheless, the pasture must not be overstocked nor grazed too closely, particularly not for any long period. Leaves enough must be allowed to grow to feed the roots of the grass.

The alterations brought about in natural grass-lands by the treading, grazing and manuring of cattle, whenever such lands are first devoted to pasturage, have often been noticed in this country. Darwin, when travelling across the pampas towards Buenos Ayres, was forcibly struck by the marked change in the aspect of the country after passing the river Salado. From a coarse herbage on one side of the river the travellers came to a carpet of fine green verdure on the other. Darwin was at first disposed to attribute these appearances to some geologic difference in the nature of the soils, but the inhabitants assured him that the contrast was due solely to the manuring and grazing of cattle. He noticed the same appearances in other localities, and remarks that exactly the same fact has been observed in the prairies of North America, where coarse grass between five and six feet high, when grazed by cattle, changes into common pasture-land.

The matter is manifestly closely related to the "bringing in" of one or another kind of grass by means of special fertilizers; though in that case it might be said that favoring influences promote the overpowering growth of certain species, while in the case of grazing cattle the grass is subjected to such molestations and long suffering as work to exclude many of the less robust varieties.

Mixing of Animals in Pastures.

A few horses or colts kept in pasture together with or after cattle, would do good in the same sense that sheep do good by eating various kinds of plants which horned cattle pass by. Herds of horses are inferior to flocks of sheep, in that the horse does not feed evenly or fairly, as the term is. But a few horses running in a large cattle pasture will keep down the rank growth of grass where the manure of the cattle has been dropped, and they will graze, too, where cattle have trampled the grass. One plan, applicable to small pastures, is to tether a horse occasionally in places where the grass is so coarse that cattle neglect it, for neat cattle will often graze readily enough on such spots after the tall grass-stalks have once been eaten down. Conversely,

when cows are allowed to run occasionally in a horse-pasture, they will put to use much herbage which the horses have neglected. In general, it may be said that any pasture which is made to carry a mixed stock of cattle, sheep and horses, will be more evenly grazed than if only one kind of animal has been kept in it.

As has been said already, some part of the popular objection to horses in pastures is clearly a tradition from the times when horses were used for carting goods in England. They were pastured by night and kept at work on the roads by day, where most of their dung was dropped. Hence they took more matter from the fields than they returned to them, and tended to exhaust the fields.

So far as the chemistry of the subject is concerned, there can be no doubt that pasturage can be more thoroughly utilized, and the fields kept in better condition, by mixtures or alternations of several kinds of animals than by any one single kind; for not only will the different species of animals eat different kinds of grasses and weeds, and eat any one kind at different stages of its development, but there is furthermore the very important consideration that, while each species of animal dislikes to feed near its own dung, it is much less scrupulous about feeding near the dung of other animals. This point has been illustrated more particularly in Volume II, in describing a custom of methodically feeding cows with horse-manure, which prevailed at one time in Norway, as well as in India and elsewhere. When we consider how much excellent grass in every pasture devoted solely to neat stock is thrown out of the account, in so far as such stock is concerned, by the droppings of the animals, the importance of adding colts enough to subsist upon this spoiled grass is manifest. It has been repeatedly noticed in Scotland, in the very best sheep pastures, that the knolls and ridges on which the sheep lie by night become very much enriched by the droppings of the animals, and produce such rank grass that sheep will not eat it; but neat cattle, on being turned in to the pasture at an appropriate season, devour this grass greedily, and it is said to be for them a highly nutritious food.

One method sometimes practised in central England was to turn in to the pastures of clover and ray-grass a certain number of store bullocks as companions to fatting sheep. These neat cattle got their chief support by eating off all those bents of ray-grass

which the sheep had allowed to shoot up, and they were thus kept in fit condition to be fattened off in stalls during the next winter. Meanwhile the sheep got a better bite simply because the pasture was kept cleared of useless stalks.

The same idea was put in practice on the low-lying rich pastures of Lincolnshire. These pastures were stocked in May in such wise that those devoted to sheep got one young steer for every twelve sheep. The number of animals allotted to the acre varied according to the quality and condition of the grass, but care was taken that the grass should be kept closely cropped, since rank herbage is apt to be inimical to the health of sheep. On the pastures devoted to fattening bullocks, one horse was allotted to every twelve beeves, but here the grass was allowed to grow more freely than in the sheep-pastures since oxen require a plentiful supply of grass, in order that they may feed quickly and have ample time left in which to ruminate. It is an old saying of English graziers that grass should be 24 hours old for a sheep and 12 days for a bullock. The tufts of coarse grass that grew upon the richer spots in the ox-pastures were mown by small portions daily, so that the cattle might eat it as it wilted. If left standing, such grass would become so rank and sour that the animals would not touch it.

Mixed Stock apt to Injure one Another.

Generally speaking, there would be little question as to the superior economy of mixed stock in pastures, if it were possible to make sure that the animals would not injure or annoy one another, and that the droppings of one kind would not be detrimental to the health of the rest. Sheep and young cattle, but not calves, are said to do well together, but neither cattle nor horses do well with sheep as a rule. Sheep among cattle are regarded as unprofitable stock, because, as has been said already, they gnaw down too closely the youngest and best of the grass. They steal from the cattle, as it were, the cream of the pasturage, and the grass upon which the excrements of sheep have recently fallen is not liked by the cattle. Marshall mentions an instance where "a good bite of grass having come up where a sheepfold had stood, cows were put in to feed it off, but they would not touch it. Horses were then turned in, and they ate the grass into the very ground."

One or two cosset-sheep that have been reared among cows will

prosper among them, and do no appreciable harm. But flocks of sheep and herds of cattle represent different interests. A few cattle that have been reared among sheep, and always kept with them, are said to be a valuable means of protecting sheep from dogs. The cattle attack the dogs and drive them from the field. A cosset-goat might perhaps do this work still better? Horses and cows are apt to annoy each other, and seriously to injure one another, for that matter, when kept in the same pasture; especially when there is but one animal of one kind against several individuals of the other kind.

Since so much has been learned of late years about the genesis of the internal parasites of animals, how many of them lurk in one animal before they come to another, and how they pass through various stages and transformations, each of which may occur in a different kind of animal, it behooves the farmer to take care how he mixes different kinds of stock in the pasture, lest he promote the growth of these parasites, and their transfer from one animal to another. Cases are on record, for example, of calves having been made sick, some of them unto death, by parasites derived from the dung of hogs with which the calves were pastured.

Distribution of the Manure in Pastures.

With regard to the droppings of neat cattle, that is to say, the dried clots of dung, it is a question how much, if anything, can be done with economy in this country towards scattering them upon the surface of the land. The urine of cattle at pasture is well disposed of. It sinks at once into the earth, and is probably distributed there as well as it possibly could be. But with the dung of large cattle it is a very different matter. When left as dropped, some plants are killed by it altogether, while the adjacent grass shoots up rank and coarse, and is notoriously unpalatable to cattle, unless it be mown and wilted, or unless it has been touched by frost.

If the dung could only be spread or scattered, no grass would be killed, and none would be made unduly rank, while the general fertility of the field would be increased. The question to be solved is, simply, Will spreading the dung pay? Possibly it might pay in some exceptional cases; but probably it would not pay at all as the general rule. The English, for their park-pastures and for lawns that are pastured, have what they call a chain-harrow, which goes over the surface of the ground lightly, scattering all

clots of dung, all mole-hills and ant-hills, and raking up moss, and airing the sod generally without tearing it. It may be worked with a single horse, and is an inexpensive and efficient instrument that greatly commends itself, excepting a certain liability to kink, though it is probably too much of a refinement to be in place upon cheap land. Perhaps a well-worn smoothing-harrow or a stiff bush might serve fairly well as a substitute for the chain-harrow.

It is a curious reflection that, while in Europe the farmers argue that pasture-land that is kept stocked with adult animals tends to improve rather than to run out, farmers in New England regard the pasturing of stock as an exhaustive process. It has been said again and again, at meetings of our agricultural societies, that the pastures have deteriorated because we have been taking away from them continually without putting anything back. This statement is clearly wrong, because too general and too emphatic. In spite of the dispersion of what are really small quantities of manure over great stretches of land, as has been said, it still remains true that the matters actually taken away from the pastures are, in most cases, almost as nothing in comparison with what has been put back again in the dung and urine of the animals. Some nitrogen has been removed, of course, in the form of wool, and milk, and flesh; and small amounts of ash-ingredients also, in the wool of sheep, the milk of cows, and the bone and flesh of growing animals; but all these ash-ingredients could assuredly have been made good by the yearly disintegration of the stones and gravel in the pasture-earth; and it must often be true that more nitrogen is brought in by symbiotic micro-organisms on the roots of leguminous plants than is taken away from the land by the animals.

Of course the loss of fertilizing matters from pastures is more serious in some cases than in others. When the pastured cattle are driven home at night and kept up in the yard or barn until morning, the land will necessarily be deprived of the manure voided by the animals during their absence from it. But in very many cases it is not such pastures as these alone that are seen specially to fail, any more than those in which the cattle are left undisturbed night and day through the summer; and the causes of the deterioration must be explained in some other way than by the theory of chemical exhaustion. The very fact that bushes, weeds and worthless grasses continue to grow on the land shows that plants can still obtain nutriment from it. Indeed, it is plain

enough in many cases that the coming in of bushes and of bad grasses is a more serious difficulty than the lack of plant-food; and it is evident, also, that droughts are very hurtful, because the good grasses suffer more during dry weather than the bad. It is certain that, if a proper supply of moisture could be insured throughout the growing season, it would be easy to bring in good grasses and to maintain them.

It is a tenet of European husbandry that, on breaking up land which has been long in pasture, there will be no need of manuring for the first set of crops that are to be taken; and a somewhat similar idea prevails in New England, in spite of all the talk which is uttered concerning the exhaustion of the pastures. It is a common practice abroad to lime such land on ploughing it, and the practice might sometimes be copied here with advantage.

Some part of the deterioration of American pastures may be due to the improper distribution of the dung and urine which are dropped upon such great wastes of land. It may be well sometimes, on this account, to fence off a favorite standing-place on purpose to exclude the cattle from it. Conversely, it may be practicable to induce the animals to loiter on a patch of inferior land, by keeping a salt-box there, or by feeding out a little meal there daily for a time. In the same sense, it may often be best to have shade-trees stand on the poorer parts of a pasture, rather than upon the richer land; though it should be said there are some farmers who maintain that shade-trees should be excluded from pastures altogether, because animals are apt to fall into the habit of spending much time in lying or loitering beneath them instead of attending constantly to their proper business of eating grass!

In cases where water has to be brought to pastures in aqueducts, it will often be practicable to place the troughs on some knoll of poor, thirsty soil, where both the drippings from the troughs and the droppings of the animals would do good service. Yet again, the grass that grows rank and tall in the spring on spots which are much resorted to by cattle, and which is in consequence rejected by them, may sometimes be mown with advantage in June, and made into hay. By so doing, a quantity of useful winter forage is gained, while the new growth of grass will commonly be freely eaten by the animals, and the place will continue to afford them good pasturage thenceforth.

Some farmers have occasionally taken the trouble to stack, upon

the dry knolls of a pasture, hay and weeds obtained by mowing the low places; in order to induce the animals to congregate at these stacks to eat or to scatter the fodder as they may please. Another plan is to strew salt on those patches of land where the grass is coarse and unpalatable, in order to induce the cattle to eat it off closely.

Overrank Grass.

Practical men often object to wet pastures, to rainy seasons, and, in general, to grass which has grown rank, somewhat in the same spirit that stable-men esteem hay from low-lying fields to be inferior to that from the uplands. In the words of Marshall, "In a wet season, grass is watery and weak; in a dry one, it is rich and substantial, a great deal of nutriment being compressed into a small compass, the superiority of quality making up for the smallness of quantity."

As regards neat cattle, the lack of nourishment in rank grass could probably be overcome by adding to the daily ration a small quantity of corn-meal or of some other concentrated fodder. Indeed, Marshall has told of an English farmer who, in a very rainy season, put within reach of his grazing cattle a supply of half-made hay. At the time in question, it was a matter of general complaint that "grazing stock, though they have this year rolled in grass, have not done well, Mr. Henton being singular in saying that his feeders have done tolerably. Indeed, his stock corroborate his assertion. He had a lot of cows on sale the 12th of August, the fattest in the show. But his management is more remarkable than his success. He 'foddered them with hay all the wet weather'; that is, he mowed the broken grass for them, beginning under the hedges and continuing to mow the coarsest patches throughout the piece. The cattle seldom touched this grass the day it was mown, but the second or third day they fell to it freely; eating it 'between whiles' in preference to grass. 'In the morning it was always the first thing they filled their bellies with.' . . . His stock consisted of about 60 head. At first, only one man was employed in mowing, etc., but before the rainy weather ceased he set on another man."

Pastures injured by Insects.

A much more important matter than the scattering of the manure is the destruction of insects in pasture-lands. It often happens that grasshoppers and crickets abound in dry pastures, and destroy

an amount of herbage of which few people have any just conception. By chance one day, as I sat reading at a closed window, I had an opportunity to see a grasshopper of moderate size attack a lilac-leaf upon a bush outside the house. The leaf was fully grown, and there was no evidence either that the insect was specially hungry or in haste, yet he disposed of the entire leaf in an incredibly short space of time. Several mechanical devices of apparent merit, to be worked by horse-power, have been invented in this country for sweeping up grasshoppers by the bushel from mowing-fields and pastures. Some of them were described in the United States Agricultural Report for 1883.

Guinea-hens, and turkeys also, are effective agents, and they may be applied methodically for abating grasshoppers. At the Paris Exposition of 1867 there was exhibited a simple contrivance for applying the turkey-cure. A high rectangular framework, set upon wagon-wheels, which was provided with suitable perches and covered with white cotton cloth, constituted the house and home of the birds. Perhaps an ordinary hay-rigging, with upright poles set at its sides, to be covered with hay-caps, would answer a similar purpose? The idea was, that a flock of turkeys should be kept in this movable pen. That it should be their home and roosting-place always. After they had become wonted to this "house" they could be transported in it, or driven before it to any field specially beset with grasshoppers, and left there until the field was cleared. The white, tent-like structure was visible to the birds from afar, and they were accustomed to rally upon it, no matter in what field it might be placed. Guinea-fowl are equally efficient with turkeys, or even more so, but ordinary hens are less serviceable, because less enterprising and less fond of roaming in strange places.

Naturally enough, the foregoing remarks do not apply to cases where flights of grasshoppers or locusts bring enormous numbers of these insects to the fields. Indeed, it has been said of such conditions in California, that turkeys are apt to die after they have eaten to excess of grasshoppers, — perhaps because of intestinal irritations or stoppages caused by the rough and indigestible legs and wing-cases of the insects.

Grub of the June-beetle.

Another insect that does much harm to lawns and to old dry mowing-fields is the white grub of the June-beetle, which, while

in the maggot state, lives underground for three years, and subsists upon the roots of grasses and other plants. The presence of this pest is indicated not only by the manifest sufferings of the grass-plants, but often by little pits upon the land which are dug by skunks that feed upon the grub.

It might, perhaps, sometimes be possible and advantageous to destroy the grub by applying some soluble corrosive fertilizer — such, for example, as a high-grade superphosphate, or the acid sulphate of potash — to those patches upon the field which are known to be beset with the grubs. Possibly the grub might be smothered or drawn out from the land by some system of mulching the bad spots heavily, as with tan bark or compost. In any event, the treated patches would have to be reseeded after the destruction of the grub. It may here be said that the whole question as to the advisability of putting corrosive chemicals upon the soil for the sake of destroying insects, worms, weeds, or fungi, needs to be studied carefully. At the first glance, it would seem as if much good might often be done by the intelligent application of such materials; but, in using them, the farmer will need to be upon his guard, lest he destroy also those helpful microscopic organisms which act to keep the soil in a good state of fermentation, and to promote its fertility.

Stocking of Pastures.

One important means of caring for pastures is the just apportionment of cattle to the area of the field, and to the amount of grass. It is not well to keep large droves upon small fields. Even of milch cows, it is said that where as many as 50 or 60 head are kept, the animals will do better if they are divided into two distinct herds. Where there are but few animals the weaklings will be much less subject to injury and annoyance, and the grass will not be so much worn by being trampled on. It will escape, too, much harm which might be caused by uneasy movements of the animals, and by their marching across it in a body when they come up to be milked. Except in the case of reclaiming a pasture which has run wild, or the occasional clearing up of a pasture, as has been said, care should be taken not to overstock the land to any such extent that the good grass will be gnawed down to the very roots, or the roots torn up. On the rich pastures of Lincolnshire the graziers are said to devote much attention to the stocking of the fields in the hot summer months. In some

seasons, when the grass grows freely, the pastures are crowded with all the stock they can carry, but towards the end of summer a gradual thinning out of the animals becomes necessary, and much care is exercised in order to keep the land in good case. The fact that some of the sheep and beeves have by that time become fat enough to be fit for market helps very much for the proper management of the land. On the other hand, there should not be too few cattle, since they would feed only upon special patches, and leave the remainder of the field to run up to bushes, weeds, or bad grasses. In case there are many early weeds in a pasture, it is well to turn in animals betimes, before the grass has become strong enough fully to satisfy them. For so long as the weeds are young and tender, they will be eaten off readily enough, and will be eaten off clean.

Number of Animals to the Acre.

Arthur Young tells of Irish pastures so rich that they will fatten 9 sheep to the acre, and it is well known in Europe that an acre of really good pasture-land will support a cow, though in this country it is a somewhat customary figure of speech to allow "four acres to a cow." There are not a few places in New England where six acres will hardly suffice for one cow, while on some of the arid pasture-lands at the West 15 to 20 acres are allowed for a single steer. It is a dictum of European writers that when more than four acres of land are required for the support of one cow the pasture is not fit for cows, but should be devoted to sheep.

CHAPTER XLI.

ENSILAGE.

It has long been customary in certain localities to preserve brewers' grains, beet-leaves, and several kinds of forage-crops, without subjecting them to any process of drying, by merely treading the fresh forage firmly into pits, or, as the French say, "silos," and covering it with earth. In recent years, the use of silos has been greatly extended, and instead of digging mere holes in the earth, it has been found to be advantageous to build the silo in the form of a high bin or compartment, in or close to the barn in which the ensilage is to be fed out to animals. At one time costly cellars or chambers of masonry were built expressly to be used as silos, but

in this country, at least, masonry has commonly been found to be inferior to wood for this purpose.

As an improvement upon the old plan of burying the vegetable matters beneath a layer of earth, a method was devised of covering the contents of the silo (known as ensilage) with planks or boards, which were subjected to pressure, in one way or another, usually by piling stones or boxes of sand upon the planks. The employment of heavy weights in this way was doubtless a matter of importance at a time when most silos were merely shallow pits or trenches that had been dug temporarily in the earth; but when high, deep silos came to be constructed, it was soon recognized that very little extraneous pressure is needed for the preservation of ensilage in a tight and well-covered bin, and that practically the significance of any outside pressure is confined to the uppermost layers of the ensilage, since the lower layers are pressed sufficiently by the mass of ensilage above them. Indeed, many farmers now maintain that heavy weights may be dispensed with, at least as regards Indian corn, and instances are frequently reported in which maize-ensilage has been well preserved beneath a simple covering of unweighted boards, or beneath layers of rushes, or bog-meadow hay, or of chopped straw, no more than a foot or two in thickness. According to S. Johnson, the question of weighting corn-ensilage is largely a matter of convenience; he suggests that it would often be cheaper and easier to put on a moderate weight of planks, etc., in case the materials were at hand, than to be at the trouble of drawing and cutting straw or hay to serve as a covering.

Ensilage in Stacks.

In some European localities large quantities of grass and of other kinds of green crops are now preserved, not in pits or bins, but in stacks. That is to say, instead of building silos proper, the practice is simply to pile up the green forage in stacks, where it is pressed firmly together, either by constantly treading or rolling the grass, especially at the sides of the stack, as it is piled on,—or by putting dead weight upon the stack, as by building a stack of hay upon it,—or by means of levers or screws acting upon chains or wire ropes which encircle the stack. To protect such stacks from rain, a light roof of boards or thatch may be placed upon them. This stacking of ensilage is said to be a device of great merit in cases of sudden necessity, as a means of saving

grass and clover, or similar crops, when continuous foul weather precludes the possibility of converting them to hay. The stack avoids the first cost of building a bin or excavating a pit, and since the crop may be piled up in the very field in which it has grown, the cost of carting the heavy green plants at a busy season may be reduced to a minimum. It needs to be said, however, that the waste of material in stack-silos is usually larger than it is in silos proper, both because it is less easy to control fermentation in a stack, and because of the unavoidable access of air to the outside of the stack, where decomposition must continually occur to a greater or less extent. According to English experience with ensilage, "The great drawback with stacks is the loss to the outsides." There is a layer from 4 to 20 inches thick on the surface of the stack which is unfit to be used as fodder. The loss on this particular account has been estimated as seldom less than 5 % of the weight of the material, even in large stacks, and frequently it is very much more than that. Losses amounting to 25 or 30 % of the dry matter of grass are common, and even those of 40 or 50 % have often been noticed.

Fermentation of Ensilage.[1]

It is a matter of experience that green vegetable matters packed firmly in a silo or tightly compressed in a stack do not ferment rapidly, and putrefy as they would do if they were to be left in loose heaps. The fermentations which actually occur in a well-ordered silo are, comparatively speaking, mild in form and small in degree. It is true that in the silo a certain amount of fermentation always occurs at first, and that the degree or amount of this fermentation may vary considerably, according to the kind and condition of the crop, and with the circumstances under which the crop has been stored. But in a well-ordered silo this incipient fermentation soon ceases after the air which was entangled in the forage has been used up. It is known, moreover, that the action of the microscopic organisms which cause fermentation is checked by the accumulation of certain chemical substances which are produced during the fermentation, notably by lactic acid, and by the carbonic acid gas which saturates the materials and tends to preserve them from decay. Perhaps it is as much for retaining carbonic acid gas inside the silo as it is for excluding the outside air that practical men insist on the importance of avoiding open

[1] Compare what has been said of the causes of fermentations in Chapter XIX.

cracks, permeable walls, and even devices for draining off water from the silo. In case the silo is built of masonry, the sides should be tightly cemented to hinder the transpiration of air and carbonic acid.

It is a familiar fact in the history of fermentations that few of the micro-organisms which cause fermentations can support the presence of any large accumulation of the chemical substances which are produced as a result of the activity of the ferment-organisms. Thus, the sulphuretted hydrogen produced during the putrefaction of albumen soon checks the activity of the bacteria to which the putrefaction was due. In the making of alcohol from sugar, and of vinegar from alcohol, the action of the yeast in the one case and of the vinegar-ferment in the other is checked, after a while, by the accumulation of alcohol and of acetic acid in the respective liquids. Even so in the silo, the micro-organisms which cause the green fodder to enter into fermentation soon become quiescent, because of the accumulation of lactic acid or other acid which the fermentation has produced.

As regards the formation of lactic acid, it has long been known that, in order to prepare any considerable quantity of this substance by way of fermentation, the materials from which it is made must be kept neutral, or no more than very slightly acid, and recent observers have noticed that the lactic ferment ceases to act in liquids that contain as much as 1.5 % of lactic acid. So, too, for the success of a butyric fermentation the materials must be kept neutral or alkaline. The germs of the butyric ferment do not develop in the presence of acids, though when once started the fermentation will proceed slowly in liquids that are slightly acid.

Generally speaking, the fermentation of ensilage will be less pronounced in proportion as air has been more completely excluded from it, by taking pains to cut the fodder fine, and by treading it into the silo firmly and carefully. During the process of fermentation the temperature of the ensilage rises considerably, — to 90°, 100°, or 120° F., or even to 130°, 150°, or 160°. At temperatures above 160° an inferior, dark-colored, or even black, "burnt" product is obtained.

Temperatures at which Acids form.

In a silo filled with well-matured fodder-corn, it is possible to reduce the amount of fermentation and the heat of fermentation to

very low terms by cutting the corn-stalks fine, filling the silo rapidly, treading the material thoroughly, and weighting it heavily. But it may often happen that favoring conditions and considerable trouble are needed in order to this result, so that practically more or less fermentation does usually occur. Many observers have noticed, moreover, and especially as regards immature corn-fodder and other kinds of crops, that when the heat of fermentation is low larger quantities of acids are formed than is the case at higher temperatures. The English chemist Voelcker has even gone so far as to admit that ensilage produced at temperatures lower than 122° is always more or less sour. This fact is so generally recognized that the terms sweet ensilage and sour ensilage are not infrequently used to characterize products obtained under such conditions that the heat of fermentation has risen to 125° or 140°, or more, or has been less than 120°. The fact of the matter appears to be that much larger quantities of acetic and butyric acids are apt to be formed at low temperatures than can possibly be the case at higher temperatures, and since both these acids are volatile their presence is made manifest to the sense of smell, while the non-volatile lactic acid cannot thus be detected and only the agreeable odor of other constituents of the ensilage is perceived.

It is known from experiments made upon solutions of sugar, or with milk, that both lactic and butyric acids form with special ease at temperatures lower than 125°. Thus, Richet observed in the lactic fermentation of milk that the fermentation (which, as many observers have noticed, is vigorous at temperatures of 85° to 95°) became more and more active in proportion as the temperature was increased up to 110°; that this activity remained unchanged between 110° and 125°, and gradually decreased at temperatures higher than 125°, though it did not wholly cease until very much higher temperatures were reached. Mr. C. E. Avery tells me that the action of the lactic ferment is at its best at 120° F. It is known that the activity of this ferment ceases at temperatures much lower than 212°, though in order actually to kill it the liquid must be heated somewhat higher than 212°. The butyric ferment prospers at temperatures still lower than those best suited to the lactic ferment. For the preparation of butyric acid, temperatures of 77° to 86° are said to be the best. At 60° the action of this ferment is simply slower than it is at 80°. It is well known also that the butyric ferment can resist a very high temperature. Ac-

cording to Fitz, a temperature of 194° F. for 5 hours, or of 176° for 7 hours, will destroy the power of the butyric ferment to cause fermentation, though it can still reproduce itself after having thus been heated. In order to kill the butyric ferment, any liquid which contains it must be heated to at least 221° F.

Air favors Hot Fermentation.

In case a silo is filled all at once with fodder-corn, which has been chopped, trodden and weighted, it will usually happen that considerable fermentation will occur, though not enough to generate much heat, and that the conditions will be favorable for the production of a certain amount of acid. But in case the chopped corn-stalks (or other forage) have not been trodden down immediately, enough air may remain entangled among them to excite a comparatively vigorous fermentation, which may cause the temperature of the mass to rise to a degree certainly unfavorable for the formation of acetic and butyric acids, and apparently not so favorable for the production of lactic acid as somewhat lower temperatures would be. Hence so small a proportion of acids remains in the finished ensilage that it seems to be sweet, by comparison.

In experiments made early in October on the preservation of rowen (grass), by compression in stacks, Wolff and Eisenlohr found, in case the grass was somewhat wilted, that it quickly became very hot in the stack and suffered a loss of from 25 to 30% of its dry matter. Meanwhile the albuminoids of the grass were so much changed that they became almost completely indigestible by sheep. Even the digestibility of the crude protein of the grass fell from 56% to 27%, and it appeared that only the amids of the crude protein and not the albuminoids were digested. On the other hand, it is not advisable that the grass should be so wet at the moment of stacking that it contains no more than 15 to 20% of dry matter, for in that event the heat of the stack would not be sufficient for the making of sweet ensilage, and a sour product would be obtained.

In any event, it is so difficult to regulate the temperature in a stack, and the loss of material is apt to be so large there that the method of compressing grass in stacks is manifestly inferior to the ordinary process of hay-making — at least in so far as concerns grass, clover and lucern. It is to be looked upon merely as a makeshift whereby a crop of grass may sometimes be saved in

rainy weather and especially in the autumn. According to Albert, the temperature in a pressed stack may quickly rise to 140° or 150° F., but soon falls to about 122° when the pressure is increased. After remaining for a long while at from 100° to 120° the temperature slowly falls to that of the external air. Wolff and Eisenlohr noticed that the digestibility of the cellulose of their stacked grass was perceptibly increased (from 62% to 71%), as had been noticed previously in brown hay made from lucern and sainfoin, but that the digestibility of the carbohydrates in the stacked grass was somewhat diminished.

Methods of filling Silos.

There can be no doubt, provided the materials are in fit condition, evenly packed, and properly covered, that excellent ensilage may be made by filling the silo quickly and closing it at once; and it is probable that the best possible results are obtained by operating in this way, for there appears to be a serious objection to the making of ensilage under such conditions that high temperatures are developed, in that the waste of material will presumably be larger in proportion as fermentation is more active. But to offset the loss of material there are certain advantages gained by the hot fermentation which attract many farmers. Not only does the "sweetness" of the product please them, but the process of filling the silo may be proceeded with leisurely, without need of any extraordinary addition to the usual working force of the farm, and the silo may finally be filled completely, i. e. to the brim. It is to be noted, however, that those kinds of fungi which are classed as moulds would be apt to grow on the surface of the pitted material if it were to be left uncovered for a longer time than one or two days. According to Miles,[1] writing of Indian corn, —

"The usual practice in filling the silo, to avoid acid fermentation, is to put in but 2.5 to 3 feet in depth of the chopped fodder in a single day, and to allow this layer to heat until a temperature of about 125° is secured. Another similar layer is then added, and left to heat in the same manner, and this process is repeated until the silo is full. From 1 to 3 days, or even more, may intervene between the filling-in of any two contiguous layers, according to the condition of the fodder and the progress of the heating process. Each layer is carefully packed at the edges and corners to completely fill all the spaces, but any trampling beyond what is required for this purpose is avoided. When there are two or more silos, the filling may alter-

[1] Miles, M., A Practical Treatise on the Ensilage of Fodder Corn. New York, Orange Judd Company.

nate from one to the other, a layer of fodder being put into one while the others are heating ; and with a single long silo, without a partition, the two ends may be treated as separate silos, and alternately filled in the same way."

In order the more readily to obtain temperatures of 122° to 125°, or more, —

"The fodder put in on the first day is not levelled at once, but allowed to remain in a loose pile in the middle of the silo until it is well heated, and the fodder for the next layer is ready to be put in. The hot ensilage is then levelled and packed at the corners, and immediately covered with the fresh fodder of the next layer. With a similar purpose in view, the last load or two of the fodder of each layer is left in a pile in the middle of the silo, to heat until ready to fill in the next layer."

It is said to be well to crown up the material somewhat at the middle in order to insure a constant pressure against the side walls while the mass is settling. Finally, a covering of cut straw or coarse hay and tarred paper is added. This cover should be well packed at the sides and corners, and a few loose boards may be laid on to keep it in place.

It should be said that several observers in this country have maintained that, for obtaining sweet ensilage, the most important considerations are that the maize-plants should be adequately mature and that air should be thoroughly excluded. Short, for example, was unable to detect any definite relation between acidity and the heat of fermentation. In some instances he obtained ensilage of excellent quality and of very slight acidity when the temperature of the silo had never risen above 80° F., while on other times ensilage of a high degree of acidity and of offensive odor was formed when the temperature had ranged as high as 150°. But as has been said, there is a common impression that — barring the inevitable waste of material — the quick hot-fermentation of maize-ensilage is favorable for "sweetness."

As an English writer puts it, the character of any given sample of ensilage depends largely upon the temperature to which it has been subjected; and the temperature may in many cases depend on the amount of pressure which has been put upon the materials at first. It is often a matter of no small importance to be able to control this matter of pressure in the early stages of ensilage-making. It has been noticed, also, in England, when silos were filled with grass, or the like, during rainy weather, that the ensilage was apt to be particularly sour, perhaps because the heat of fer-

mentation was kept at a low degree by the evaporation of the extraneous moisture on the wet grass.

The influence of air in exciting hot fermentation is well illustrated by the experiment of Guyon — described in the chapter on Manure — in which the temperature of manure left to ferment in the air rose to 162° F., while the temperature of an equal quantity of the manure kept in a close box hardly rose to 59° F.

The Hot Fermentation in Silos.

Possibly a just conception of the hot fermentation which occurs in ensilage that has been loosely stowed may be got by reasoning from analogy, and comparing this fermentation with one which is known to occur when yeast is made to act upon a solution of sugar in presence of much air. There is an experiment of Pasteur, for example, in which he mixed brewers' yeast with a thin layer of sugar-water in a large basin in such wise that the liquid should be exposed to a great excess of air. It was noted that under these conditions the yeast-plant developed with peculiar rapidity, that most of the sugar in the liquid was used up in building new yeast-globules, and that comparatively little alcohol was formed. That is to say, the excess of air was specially favorable for the growth of yeast, but not for the production of alcohol. Much carbonic acid gas was developed meanwhile, in addition to the small amount of alcohol. It is not impossible that something analogous to this mode of action may occur in the hot fermentation of ensilage, and that the small amount of acid formed may depend upon a similar cause. The notion held by some farmers, that temperatures of 125° or 130° are fatal to the lactic ferment, is plainly erroneous, for it is known that this organism can still act at these temperatures, though somewhat less vigorously than at 120°. As for the alcoholic ferment (yeast), which may probably enough play a part in the changes which occur when ensilage is left in loose heaps, authorities assert that it is killed at temperatures of 140° or 150°.

It is to be remarked that yeast might act in the manner illustrated by Pasteur's experiment, just now mentioned, or circumstances might sometimes permit it to grow and produce an appreciable quantity of alcohol, as in the ordinary processes of fermention for making beer or spirit. Indeed, since it has been shown by the French physiologists that alcohol may be formed by living plants, placed in an atmosphere of nitrogen, as well as by

ripening fruits, it is credible enough that this substance may sometimes be formed in silos just after they have been filled, for, as Dehérain has said, the living cells of plants, when removed from contact with oxygen, may act like beer-yeast to decompose sugar into alcohol and carbonic acid.

Beside the lactic, butyric, valerianic and acetic fermentations which occur in silos, there is another kind known as the viscous fermentation, which may precede the others. It is specially apt to develop in the case of beets and turnips. After the initial fermentation — which always occurs in some degree when ensilage has first been stowed — has run its course, the vegetable matter suffers no further changes of moment, provided the material has been well packed and freed from air-spaces, until such time as it is taken from the silo, and left in contact with the air. Then new fermentations soon set in, which may change both the odor and the taste of the material. It is possible, indeed, that even the lactic and butyric acids which are contained in the ensilage may now be consumed and destroyed by a new set of micro-organisms.

The Acetic Fermentation.

The so-called acetic ferment which is habitually made use of in household economy, and at vinegar factories, for converting diluted alcohol into acetic acid, is abundant everywhere, especially during the summer months, and since it has power to oxidize not only alcohol, but sugar also (C. E. Avery), it may readily do harm in the silo. Ordinarily, very considerable quantities of acetic acid are speedily formed in heaps of ensilage which have been left lying in contact with the air. And a somewhat similar condition of things may come to pass, even before the silo is opened, in case many air-spaces have been left between the stalks of forage at the time of packing. Samples of ensilage have been described which were so extremely sour, from the presence of free acetic acid, that they were held to be worthless. It is to be presumed, indeed, that the liability of ensilage to become unduly sour when prepared at a low temperature may depend largely on the activity of the acetic ferment. But hot fermentation in a silo would destroy the acetic ferment, since it cannot bear temperatures higher than about 104°.

It may be accepted as a general rule that if much air were left in the interior of a silo, or if air could enter it from without, a

variety of hurtful fermentations and putrefactions might occur, and practically destroy the ensilage. A moment's consideration of what happens frequently in hay-making, when continued showery weather compels the farmer to leave bunches of hay unopened in the fields, will illustrate the importance of keeping ensilage tightly impacted and protected from access of air. It may here be remarked that the blackening of hay thus spoiled in the making is to be attributed simply to the fact that some of the chemical products formed during the harmful fermentations to which the hay has been subjected, are dark-colored.

As a point of scientific interest, the fact may be mentioned that nitrates are deoxidized by the fermentations which occur normally in the silo. When leaves (as of beets and turnips) that happen to be charged with nitrates are preserved in silos, the nitrates are destroyed. In experimenting on this matter, Kellner noticed an actual loss of nitrogen somewhat larger than the quantity of this element contained in the nitrates in the original leaves.

Mouldiness in Silos.

Care needs to be taken to avoid waste at the sides and corners especially of the silo, and at the surface also, for it is to be noted that, beside those fermentations which in some sort, and within due limits, are to be regarded as normal and necessary, mouldiness may occur and spoil more or less of the ensilage at the top and in the corners, and wherever air may leak in. It has happened not infrequently, on opening silos, that the ensilage has been found to be mouldy and worthless to a depth of several inches beneath the covering of planks, and this surface mouldiness is said to be specially apt to occur when fodder-corn has been allowed to become so mature and dry before pitting it that the material cannot be packed solidly at the surface. It is to avoid this surface waste that many farmers cover their ensilage with a layer of cheap hay or straw one or two feet thick, which had better be trampled down firmly, especially at the corners and edges of the silo. This layer of straw speedily becomes saturated with moisture from below, and shields the ensilage proper from contact with the air. If time can be spared, it would not be amiss to examine this straw layer occasionally, and to keep it pressed down tight until the contents of the silo have ceased to settle. It is manifest that, by properly covering and pressing the surface of the ensilage, very little mouldiness can occur there, and it is said,

indeed, that in a well cared-for corn-silo the amount of fodder spoiled at the surface should not amount to more than 2 % of the original weight of the material. (Kuehn.)

Loss of Material in Silos.

Generally speaking, it is not at the surface of the silo nor through mouldiness that the chief waste occurs. On the contrary, the loss of material in converting forage to ensilage is caused, for the most part, by fermentations due to imperfect exclusion of air at the beginning of the process. Chemists who have specially studied the subject have repeatedly observed large losses of the dry matter of the forage. Thus a loss of 56% has been noticed in the case of lupines, and 27 % in that of lucern, 31 % in the case of red clover, and even 43 % in the case of some mown clover that had been heavily rained upon. As regards Indian corn, losses amounting to 33 and 35 % have been observed, though when proper care is exercised the loss from corn-ensilage need not be more than half as large as these amounts. In some scientific experiments made in the small way, in barrels, losses no larger than 3 or 4 % have been recorded. In a carefully conducted experiment on fodder-corn, which was cut to lengths of one-third of an inch, and was examined after it had lain in the silo during six months and a half, Kuehn and Menzel found that there had been lost from the original forage, —

14.50 % of water,
23.39 % of dry matter,
14.72 % of nitrogenized compounds,
34.22 % of non-nitrogenized matters other than cellulose, and
21.54 % of cellulose;

while as regards matters soluble in ether — such as are usually classed as "fat" — there had been a gain of 36.36 %, because of the formation of lactic and butyric acids, which are soluble in this liquid.

Armsby and Caldwell, operating upon Indian corn cut when the grain was in the milk, have contrasted the losses which occurred accordingly as the material was packed in a silo or dried in the field. They found that there was less waste of food material in the silo than in the process of field-curing, and they have drawn up the following table of averages from the results of their own and other American experiments made previous to 1890.

Per Cent of	Lost in Silo.	Lost by Field-curing.
Dry matter	17.78	20.34
Ash	0.57	2.98
Protein	1.66	0.91
Crude fibre	3.85	5.62
Non-nitrogenous matters	13.49	15.54
"Fat"	0.55	0.08

Woll states, as the average results of trials made during 4 years, that the loss of dry matter from green fodder-corn cured in the field and left out for a long time was 24 %, while the loss of dry matter in the silo was less than 16 %. The loss of protein was respectively 24 % and 17 %.

Speaking in general terms, it may be said that the normal fermentation in a silo bears heavily upon the carbohydrates of the fodder, notably upon the sugar contained originally in the plant and upon starchy matters which are changed to sugar by the action of diastase, as in the germination of seeds and the "mashing" of grain for making alcohol, while the albuminoids also are more or less involved. It is a matter of recorded knowledge that sugar, starch, cellulose, gum, the vegetable acids, and albuminous matters are all susceptible of undergoing the butyric fermentation, either directly or indirectly.

Loss of Albuminoids in Silos.

With regard to the waste of nitrogenous constituents, it is known that a certain proportion of these matters is lost as a result of the normal fermentation of the ensilage, and that small amounts of amids, of one kind or another, may be formed in the silo from the albuminoids of the forage, so that the amount of nitrogenous substances in ensilage is not only smaller than it was in the original forage, but is often of somewhat inferior quality also. E. Schulze has insisted upon a fact observed long ago by Boussingault, that a portion of the albuminoid matter in green plants changes to amids — notably to asparagin — when the plants are kept for some time in the dark, and has shown that this change actually occurs in the silo. The transformation now in question appears to be due to physiological action in the living cells, and to cease when the cells die.

Schulze noticed of red-clover plants standing in water in the dark, that the albuminoid nitrogen decreased from 3.22 to 2.47 % in 8 days, while the non-albuminoid nitrogen increased from 0.89 to 1.9 %. In the case of oats similarly situated, albuminoid ni-

trogen decreased from 3.51 to 1.46%, and non-albuminoid nitrogen increased from 0.61 to 3.04%; while timothy-grass showed, in three days, a decrease of albuminoid nitrogen from 1.81 to 1.61%, and an increase of non-albuminoid nitrogen from 0.16 to 0.49%. In another experiment, timothy-grass packed in jars showed a decrease of albuminoid nitrogen from 1.82 to 1.09% in 10 days, and was then found to contain as much asparagin as amounted to 1.5 of the dry matter of the grass, although the fresh grass contained no trace of asparagin. Similar results were obtained with other kinds of grasses, a marked increase of amids and decrease of albuminoids being noticed soon after the materials were packed in the miniature silos.. It was noticed, furthermore, that in the silo the amids may speedily be changed to ammonium salts by the action of ferment organisms. Indeed, this destruction may be so complete that on opening a silo no amids can be detected in the ensilage, but, in place of them, ammonium salts. It is true, also, that ammonia is sometimes produced directly from albuminoids by ferment action, and it has been observed repeatedly in silos filled with clover, beet-leaves, and other materials rich in nitrogen, that considerable quantities of ammonia are apt to be formed, and that noteworthy losses of albuminoid matters may occur from this cause. Even in a silo which had been filled with grass, Schulze found that about 34% of the total nitrogen was in the form of non-albuminous matter, though no asparagin could be detected. It would appear, however, that very little ammonia is formed in silos filled with Indian corn, or beet residues (from sugar-making), or other materials poor in nitrogen.

Use of Germicides in the Silo.

It was customary in Germany, long ago, to strew salt between the layers of ensilage as it was put into the crude earth-pits of those days; and good results were obtained, also, many years ago, in experiments made to test the advisability of putting slaked lime upon beet-pulp in silos. There can be no doubt that this idea of checking fermentation by means of chemicals may have real merit in some cases. Thus, in a highly successful experiment made in Sweden by Alex. Mueller, bisulphide of carbon was employed as the germicide agent. A lot of mown grass which, through foul weather, had begun to decay as it lay on the ground, was thrown up into a heap or stack, together with a quantity of buckwheat and sunflower plants, of the leaves of cabbages, the tops of beets

and some small roots, and some straw and chaff; and the several layers of the heap were sprinkled with bisulphide of carbon during the process of building it. When the stack came to be opened, the fodder was found to be a compact, well-preserved mass which was readily and greedily eaten by cattle. The odor of the bisulphide had completely disappeared. Mueller thinks it probable that good ensilage might have been made in this way from the rotting grass alone if it had been treated with the bisulphide by itself, without the addition of the other materials.

Digestibility of Ensilage.

As to digestibility, it has been thought by most observers that there is no great difference between that of the constituents of ensilage and of field-cured forage, though something must depend, of course, on the character of the original plants; and it is to be remembered that the acids in ensilage may often help digestion by supplementing the action of the acids in the gastric juice. In respect to Indian corn, Armsby offers the following tentative conclusions: The digestibility of green fodder-corn is diminished somewhat in the silo and by drying in the field, and to about the same extent in both cases. The albuminoids in corn-ensilage are somewhat less readily digestible than those in green fodder-corn, and a considerable proportion of the original albuminoids are converted in the silo into less valuable forms, while the digestibility of the remainder is reduced. It sometimes happens that the digestibility of the cellulose in green fodder-corn is considerably increased in the silo, though this result is obtained only when the loss of material by fermentation is so large that the cellulose is finally attacked, and it is reached at the cost of a diminished digestibility of every other important constituent of the plant.

Kellner found that the digestibility of crude protein was considerably higher — 8.6 and 4.6 % respectively — in ensilage made from a hard, coarse grass, *Imperata arundinacia*, and from buckwheat, than in the original plants; and that there was a slight diminution of the digestibility of this constituent in ensilage made from ray-grass and turnip-leaves. He argues that, in the case of rough forage, enough cellulose is destroyed in the silo to open up the contents of the cells of the plant, and to lay bare their contents for the better action of the digestive fluids in the animal body. With regard to albuminoids, Kellner urges that in rough fodders, poor in nitrogen, the digestibility of these substances may be increased, like

that of crude protein, and for the same reason. Morgen has found this to be true of the diffusion residues of sugar-beets, and Kellner has studied it more particularly in the grass Imperata. But in more highly nitrogenous fodders — such as ray-grass, buckwheat, and turnip-leaves — which lose considerable quantities of albuminoid matter in the silo, Kellner found that the percentage digestibility of the albuminoids which are left after fermentation is lower than that of albuminoids in the original forage. Naturally enough, in these plants, rich in nitrogen, it is the tenderest and best of the albuminoids which become involved in the fermentations of the silo, whence it follows that the residual unfermented portions must necessarily be somewhat less easy of digestion.

Ensilage is normally somewhat Acid.

When a silo is opened, its contents usually exhibit a slight acid reaction, though there are exceptions to this rule, for sometimes — especially in the case of clover and other leguminous plants — the reaction may become alkaline from the presence of products of the decomposition of albuminous matters. (Kuehn.) These basic products neutralize and overpower the acids which were formed at first. Ordinarily, however, even the sweetest ensilage contains some free acid, the amount of which may range from as little as 0.02% to 2% or more. It is said that corn-ensilage as made nowadays from well-matured stalks almost always turns out to be less acid than that made formerly from younger stalks that were soft, green, watery, and comparatively poor in starchy matters. Possibly the large amount of water in the young stalks may of itself have been sufficient to keep down the heat of fermentation to a degree lower than that most favorable for the production of "sweet ensilage"?

Opening of Silos.

It is well not to begin to feed out the contents of a silo until 6 or 8 weeks after the materials have been stored, or until fermentation has ceased. As a matter of course, it usually happens that several months elapse after the filling of a silo before it is opened. As regards Indian corn, at least, it is known that silos may be left unopened for 2 or 3 years without any serious loss or waste other than the interest on the capital lying dead. Indeed, it is accounted one great merit of corn-ensilage that reservoirs of it may be kept during long periods, to be opened only in times of dearth. Clover-ensilage, on the contrary, and in general that made from plants

rich in nitrogen, should not be kept too long. When a silo is opened, it is important not to take out from it at any one time more of the ensilage than can be fed out in the course of a day, lest the loose material suffer harm through fermentation. Moreover, in removing ensilage from a silo care must be taken to proceed in such wise that no large surface of the matter left in the silo shall long be exposed to the action of the air. If ensilage were to be left uncovered for several days, moulds would grow upon it, and the surface layer might decay. Hitherto it has been customary to cut down the ensilage from the front of the silo in narrow vertical strips or sections, though not a few farmers now prefer to take off horizontal layers from the top of the mass rather than to cut off slices from top to bottom. In either case it is said to be well to build the silo of such shape and size — as related to the number of animals to be fed — that a fresh layer several inches in thickness will need to be taken off every time the animals are fed. In this point of view several small silos will be found to be more convenient than a single large one. In England, in the case of grass-ensilage, it is thought to be important to cut down vertically, and not to take off the material in horizontal layers, because weights would have to be placed continually on the unconsumed ensilage in order to prevent it from passing into the acetic fermentation.

Maize-ensilage.

In regions where Indian corn can be grown readily, there are several strong incentives for saving this crop in the form of ensilage. It is easy to grow enormous quantities of fodder-corn on comparatively small areas, and methodically to store the crop in silos in the short days of autumn and in dull or threatening weather, and this advantage is particularly marked in regions where the climate is normally unfavorable for the curing of fodder-corn in the autumn. But the farmer will naturally shrink from the task of curing large quantities of corn-fodder at that season by the method of drying, because of the risks of damage and interference through foul weather, and because of the uncertainty as to how much labor will have to be expended in handling the sheaves, and of the difficulty of obtaining laborers at times when they are needed.

The hauling and handling of the large quantities of water (80 or 90%) in green corn-stalks at the time of pitting them is of course a great disadvantage, though it appears to be more than offset by the fact that this labor admits of being methodized, and that

it can be applied with comparatively little reference to the weather. The rehandling of the ensilage when it is fed out is not specially laborious, because no very large amount of material is moved at any one time ; and there is no little advantage in having a succulent material so palatable as ensilage is, to give variety to the winter food of cattle.

Another advantage to be credited to ensilage is the fact that it is eaten up clean by cattle, while no small proportion of the buts of dried corn-fodder commonly goes to waste, even in the most favored localities. In experiments made by Shelton in Kansas, cows fed upon chopped dry corn-fodder admixed with meal, rejected 31% of the fodder, although it was of excellent quality and had been placed in tight mangers. The waste would undoubtedly have been much larger if the fodder had been thrown down upon the ground before the animals. Even in respect to some part of the buts of the stalks which were eaten, Shelton suggests the question whether the cows could have derived much benefit from the hard, dry, woody fibre which they had been tempted to eat through the small quantity of adhering meal. It should be mentioned, however, that the corn-fodder grown in Kansas is said to be usually more stalky and less leafy than that grown in the Eastern States.

At the moment of filling the silo it is customary to cut the corn-plants to lengths of an inch, or three-quarters of an inch, or half an inch, — some say two inches, though Goffart has urged that it is well to cut the stalks to lengths of one-third of an inch. When the fodder is thus cut, even to two-inch lengths, the material is easily handled, it packs closely, and the air which would naturally remain in the spaces between the corn-stalks can be pretty thoroughly expelled. But the cutting is not absolutely necessary, and not a few farmers have dispensed with it, although it is known to be highly advantageous in that the cut material lies closer in the silo, takes up less room, is more easily stowed away and compressed, and much more readily handled when it comes to be removed. Every one admits, moreover, that when long corn-stalks are packed in a silo they must be trodden down very firmly, and that care must be taken to avoid air-spaces between the stalks lest the ensilage should become mouldy around these spots of air. For other crops than Indian corn, notably for grass, it may well be questioned whether chopping is necessary. It is not practised, for example, when ensilage is stacked.

American experience has taught very decidedly that it is best, as a general rule, to allow the corn-plants to become tolerably mature before putting them in the silo. There are, in fact, very good reasons why mature plants should be preferred, for it is known that there is an enormous accumulation of useful carbohydrates in the corn-plant during the later stages of its growth. Roberts and Wing noted an increase of more than 200% of dry matter, chiefly carbohydrates, between the times of the blossoming and ripening of corn; and Ladd found that "from the date of full tasselling until ripe the dry matter increased 4.8 times, from 1,619 lb. to 7,918 lb. per acre. From full silking until ripe the increase in dry matter was 2.5 times." Moreover, as has been pointed out by F. L. Stewart, the accumulation of cane-sugar in grain-bearing corn-stalks is uniformly progressive after a certain period, and reaches its maximum just before the grain begins to glaze or harden. Practically, it has been found that the more mature the grain is while the stalks remain green, the better and sweeter the ensilage will be, and it is now a common practice as regards flint-corn not to cut the stalks until the grain has begun to glaze, or has just passed the glazing stage, while dent-corn is allowed to stand until the kernels are well dented. It is with maize much as it is with oats that are to be mown for hay. In order to obtain a large yield, and a thoroughly satisfactory product, neither of the crops should be mown before their seeds are in the milk. Not only will a very much larger yield of fodder be got in this way from the acre of land, but there is a marked advantage in putting crops in a silo when in such condition that they can hold all the moisture which they contain. According to Miles, "When immature fodder-corn is ensilaged, whether from thick seeding or premature harvesting, the excess of water it contains is a real source of annoyance and probable loss. From the weight of the superincumbent mass the juice is pressed out of the ensilage in the lower half of the silo, and there is towards the bottom an accumulation of liquid containing more or less of the food constituents of the plants which cannot be disposed of to advantage." To dry off this moisture in the field after cutting the plants, before putting them in the silo, would involve considerable trouble. On the other hand, it is not well that the crop should be allowed to get so mature that the stalks have become somewhat dry, and there is a risk that this result may happen in case the harvesting should be delayed through

press of other farm work, or by bad weather. Since corn-stalks packed in a silo when too dry are apt to "fire-fang" and be spoiled, some farmers have found it advantageous to sprinkle the dry chopped stalks with water, to fill the silo rapidly, and to weight the material heavily without allowing time for it to "heat."

Heavy Yield of Corn-fodder.

When cut after ears have formed, from 15 to 30 tons of green fodder-corn to the acre are usual crops, 25 tons being not uncommon; even 40 or 50 tons are said to have been obtained occasionally. In the following table is given Armsby and Caldwell's comparison of the yield per acre of dry matter and of digestible matter from a two-ton crop of timothy-hay, and from a small (15 ton) crop of fodder-corn, according as it was fresh, dried, or pitted.

	Timothy-hay. lb.	Ensilage. lb.	Corn-fodder. Fresh cut. lb.	Corn-fodder. Dried. lb.
Dry matter . . .	3,592	6,100	6,835	5,401
Digestible matter .	1,888	3,660	4,351	3,388

A crop of 19 tons to the acre of green corn-fodder obtained by these observers in a previous year, and saved as ensilage, was estimated to have yielded fully 4,000 lb. of digestible matter to the acre; and several American observers have obtained more than 7,000 lb. of dry matter to the acre.

As has already been mentioned, in the chapter relating to the Growth of Crops, F. L. Stewart has argued that the most profitable use of the maize-crop will be to pluck the ears soon after grain has begun to form in them, in order that cane-sugar may subsequently accumulate in the stalks, to be extracted in due course, while the plucked ears and the tops, in their turn, will be saved as ensilage.

On farms where large quantities of sweet corn are grown to be sold in the ear, — either for household use or for canning, — it has been found advantageous to preserve the corn-stalks in silos. Generally speaking, this practice would hardly be applicable to the stover of a ripened crop, though some farmers have succeeded in ensilaging dry corn-stalks (chopped) by putting them in the silo beneath and between layers of green immature fodder-corn, which had been sown late for the purpose. Perhaps rowen might here be used instead of the green fodder-corn? Indeed, if a gas-tight silo were to be filled almost to the brim with dry corn-stalks or with

stover, and then completely filled with rowen-grass or some other heavy green crop, the pressure exerted by the latter and the carbonic acid generated by it might perhaps be competent to preserve the stover, and prevent it from decaying or becoming mouldy.

Although most of the experience hitherto published in regard to ensilage has been acquired in temperate climates, this method of preserving corn-fodder would seem to be well adapted for use in some Southern countries where neither grass nor clover can be counted on for feeding stock. In several of our Southern States the scarcity of winter food for cattle is a great obstacle to the rearing of them, and to the obtaining of manure for the purpose of maintaining the fertility of farms. It is said of some localities, as of Louisiana, that even red and white clover cannot be grazed after the beginning of May, because they salivate the animals. (Russell.) In these regions, corn-fodder has always been a chief resource, and the packing of it as ensilage — to be fed out in conjunction with cotton-seed-meal — may possibly become an habitual practice. An old remark of Gasparin, that in warm countries annual clover (T. incarnatum) may well be associated with crops of millet or of fodder-corn, deserves to be studied anew as a possible means of obtaining mixed ensilage, well balanced in respect to nitrogenous constituents and carbohydrates.

Clover-ensilage.

In Germany, clover, lucern, and other leguminous crops are often saved as ensilage, though it is recognized that, when the weather permits, they had better be dried to hay. There are experiments which show that serious losses of digestible albuminous matters may occur when these highly nitrogenous crops undergo fermentations in silos. But in seasons of continuous rain the ensilaging of clover-crops may be the salvation of the farmer; for, no matter how heavily it may be raining, clover may be stored with success in silos, if only the workmen can hold out to mow and carry it. Even when clover has lain in swaths for a day or two, it will still make good ensilage, especially if it be packed layer by layer with freshly mown clover; but clover which has been considerably dried, and then wet with rain, is apt not to make well in the silo. (Kuehn.) And yet it had better be put in a silo than left to rot on the ground. In the words of Kains-Jackson, "It is now proved that fodder, grass, clover, tares, etc., when already damaged — half spoiled — may be saved from further de-

struction, and become in a stack, under regulated pressure, useful stock-food." European writers urge that it is best to carry crops to the silo as soon as they have been mown, and not to allow them to wilt in the field. Even crops wet with dew or rain, they say, had better be stored at once, while they are fresh, and not be suffered to wilt. But some American experimenters maintain that fodder-corn partially dried before packing in the silo gives equally good ensilage at a reduced cost.

Generally speaking, grass had better be dried to hay than made into ensilage, unless the weather is foul. But rowen-grass may well be stored in silos, because of the difficulty of making hay in the autumn, and a similar remark will apply to coarse weedy herbage, such as might hardly be eatable if it were made into hay. In Europe, rough grass mown at the sides of ditches, walls and hedges has repeatedly been made into ensilage with success, and so have nettles, brakes, sedges and rushes, as well as the vines of peas, beans, hops and vetches, the tops of beets, turnips and carrots, chicory-leaves, and the like. It is recommended, however, when rough grass is to be made into ensilage, to mow it somewhat earlier than would naturally be done in case it were to be made into hay. As an aid to the destruction of weeds on extremely foul land, it has been argued, also, that a succession of smothering crops may be grown, to be preserved in silos together with the attenuated and unripe weeds which have struggled to make head among them. Thus a decided cleansing effect might be produced in certain cases, and no inconsiderable amount of excellent fodder be gained, by taking a crop of oat-forage, sown thick, or of oats and peas, to be followed by Hungarian grass, and that by barley, in case the season should permit, or by rye; all to be mown so early that few weeds would have time to ripen their seeds. Another plan would be to start the succession of crops in the autumn with rye, and to have Hungarian grass and barley follow the early-cut rye.

Root-crops, or potatoes that have been frozen, may readily be saved in silos, and so may potatoes which have become infected with the fungus which causes the so-called potato-rot. The roots or the potatoes may be cut or crushed in order that they may be packed firmly in the silo, or, if convenient, the potatoes might be steamed and then packed in hogsheads or tight boxes. Apple-pomace, also, and the residues from starch-factories and from beet-sugar works may readily be saved as ensilage.

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